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FINAL REPORT

NEW DRIFT REDUCING ATOMIZATION TECHNOLOGIES - IMPLICATIONS FOR WEED CONTROL IN DIRECT SEEDED SYSTEMS

19960180

Funded by
The Agriculture Development Fund
March 2000

Prepared by: Agriculture and Agri-Food Canada

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100-05039/

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Agriculture and Agri-Food Canada
Research Branch

Canada

Saskatchewan Agricultural Development Fund
ADF Project 96000180, Res 61BV

New Drift Reducing Atomization Technologies - Implications for Weed Control in Direct Seeded Systems

Final Report

March, 2000

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Abstract

Three years of field and laboratory experiments were conducted to study new low-drift spray technologies, demonstrate their features to applicators, and evaluate their impact on herbicide efficacy. Overall results indicated that weed control with low-drift atomization systems depended on herbicide and weed species. Weed control was typically better for glyphosate than glufosinate-ammonium. Glufosinate-ammonium was relatively insensitive to application method, providing control similar to the standard nozzles in most cases. Although glyphosate control was better overall, control was frequently affected by application method: a low-drift adjuvant typically improved control, whereas very coarse sprays from some low-drift nozzles reduced control, but never below commercially acceptable levels. Spray retention on simulated weeds was similar for all application methods. Results of these studies generally support the use of low-drift technologies with non-selective herbicides. Caution is advised to avoid very coarse sprays on weeds which are difficult to control.

Executive Summary

- Three years of field and laboratory experiments were conducted to study new low-drift spray technologies, demonstrate their features to applicators, and evaluate their impact on herbicide efficacy.
- In all years, field experiments were conducted near Saskatoon and Melfort, SK, with demonstration plots near Indian Head and Melfort, SK in 1997.
- Three experiments were conducted.
  - Experiment 1, conducted in all three years, compared five low-drift atomization systems, each at 100 L/ha: (a) a conventional spray (TeeJet XR8002), (b) low drift nozzle #1 (Turbo TeeJet TT11002), (c) low drift nozzle #2 (TurboDrop TD110015 venturi nozzle), (d) a twin fluid nozzle (AirJet), and (e) an adjuvant spray (same as (a), but with drift-reducing polymer, "DR2000" at 1 g/L, added.
  - Experiment 2, conducted at Saskatoon and Melfort in 1998 and 1999, compared 8 venturi nozzles to a standard flat fan using glyphosate and glufosinate-ammonium.
  - Experiment 3, conducted at Saskatoon in 1997, 1998, and 1999, studied the effects of low-drift adjuvants ("DR2000" at 0.5 g/L and "Array", a mix of DR2000 and ammonium sulphate, at 8.9 g/L) on glyphosate efficacy.

- All systems were evaluated on tame oats, oriental mustard, and tame buckwheat using glyphosate (Roundup Original) and glufosinate-ammonium (Liberty). For Experiment 1, herbicides were applied at 4 non-zero rates each (1 x, 0.5 x, 0.25 x, and 0.125 x, where x was 440 g ae/ha for glyphosate, and 500 g/ha for glufosinate-ammonium). For Experiment 2 and 3, herbicide rates were 1 x and 0.5 x.

- Overall results indicated that weed control with low-drift atomization systems depended on herbicide and weed species. Weed control was typically better for glyphosate than glufosinate-ammonium.
  - All atomization methods in Experiment 1 provided equivalent weed control for glufosinate-ammonium in all years. For glyphosate, atomization method significantly impacted weed control 75% of the time, with DR2000 twice enhancing oat control and once reducing mustard control. The AirJet nozzle reduced oat control in two years.
  - In Experiment 2, various venturi tips provided good weed control for glufosinate-ammonium at both Saskatoon and Melfort. Mustard control was reduced significantly once with one venturi nozzle. For glyphosate, all tips performed similarly 66% of the time. When differences occurred, it was usually the coarsest venturi sprays that reduced weed control slightly.
  - For Experiment 3, low rates of low-drift adjuvants tended to improve glyphosate performance on all weed species, although not always significantly. These adjuvants had surfactant-like properties, and with Array, water conditioning properties, that were likely responsible for efficacy enhancement.

- In summary, low drift nozzles were able to obtain commercially acceptable weed control in most cases for both glufosinate-ammonium and glyphosate. When control was affected, low-drift nozzles usually caused slight efficacy reductions which occurred primarily with the coarsest sprays and the most difficult-to-control weeds.

- Media and producer interest has been very strong in this area of research, and research results have been presented at over 50 extension and scientific meetings, 12 field tours, through 8 publications (3 posters presented at scientific conferences), and in 23 media interviews and stories.

Technical Report

Background and Project Objectives

Spray drift continues to be a major concern for applicators throughout Canada. Factors leading to greater frequencies of drift complaints include increased use of non-selective herbicides, products with greater activity, more diversification to special crops which are herbicide sensitive, as well as time pressure to complete a spray application. Drift incidents are damaging to agriculture, and their settlement is both time consuming and costly.

Spray drift losses from the treated area of 15% of the applied amount have been documented in Saskatchewan with low-volume, high travel- and wind-speed applications (Wolf et al., 1993, Grover et al., 1997), although drift values of approximately 3% are most common (Wolf et al., 1993). Spray drift can be reduced by emitting a coarser spray, and low-drift atomizers delivering slightly coarser sprays have been shown to reduce spray drift by 50% compared to conventional nozzles (Grover et al., 1997).

Recently, new nozzle technologies have been introduced into Canada which promise to even further reduce off-target spray drift. For example, scientific studies have shown "venturi" nozzles to reduce drift by over 90% (Alberta Farm Machinery Research Centre, pers. comm). Unfortunately, little is known about the impact of very coarse sprays on product efficacy. Traditionally, coarse sprays have been considered to result in reduced efficacy because large droplets provide less "coverage" than finer sprays. However, unique designs in nozzles and adjuvants promise to reduce drift without the loss of efficacy.

The limiting factor to low-drift nozzle adoption is lack of knowledge in efficacy performance. Applicators are reluctant to use application methods which may reduce pest control, for which they assume all risk. To lower this risk, this research project attempted to develop knowledge to support the use of these application alternatives where appropriate. Initial work sponsored by the Expert Committee on Weeds (ECW) has suggested that venturi nozzle sprays provide acceptable weed control if used properly, but cautioned that reduced herbicide efficacy on grassy weeds may occur with very coarse sprays (Wolf, 2000).

Integration of new "low-drift" technologies into Saskatchewan agriculture represents a proactive step in providing stewardship in our agricultural practices. Adoption of drift reducing application methods will only be successful if reliable and efficient weed control can be maintained. Ultimately, application techniques which simultaneously fulfill the objectives of low

drift and good efficacy can be integrated into label recommendations to provide applicators with positive alternatives when drift risk occurs.

The objectives of this research were to explore low-drift application methods for Saskatchewan conditions, with specific emphasis on herbicide performance. Three experiments were conducted: Experiment 1 identified a variety of new low-drift application methods. Experiment 2 explored the venturi nozzle technology in detail. Experiment 3 explored low-drift adjuvants in detail.

Methods:

Experiment 1: Low Drift Atomization Methods.

Five atomization systems were evaluated, each with two herbicides (glyphosate, formulated as Roundup Original and glufosinate-ammonium, formulated as Liberty):

a) **Conventional spray**: TeeJet XR8002, 100 L/ha @ 275 kPa (XR),
b) **Low drift nozzle #1**: Turbo TeeJet TT11002, 100 L/ha @ 275 kPa (TT),
c) **Low drift nozzle #2**: TurboDrop nozzle TD110015, 100 L/ha @ 550 kPa (TD),
d) **Twin fluid nozzle**: AirJet nozzle, 100 L/ha, 70 kPa air and 180 kPa liquid pressure (AJ),
e) **Adjuvant spray**: Same as (a), but with spray-thickening adjuvant added (Rhodia DR2000 @ 1 g/L) (DR2000).

Herbicides were applied at 4 rates. For glyphosate, the rates were 440 g ai/ha, 220 g ai/ha, 110 g ai/ha, and 55 g ai/ha. For glufosinate-ammonium, the rates were 500 g ai/ha, 250 g ai/ha, 125 g ai/ha, and 63 g ai/ha. Nozzles were calibrated prior to spraying by collecting spray output from each tip for 1 minute, measuring in a graduated cylinder, and averaging across all nozzles in the boom. Nozzles which deviated more than 5% from the mean were replaced. Travel speeds were calculated based on total boom output, and the correct tractor speed was determined with timed runs over a set distance. Boom height was set to 50 cm above the target plants.

Experiment 2. Venturi Nozzle Comparison.

Eight low-drift venturi nozzles were compared at Saskatoon and Melfort in 1998 and 1999 (seven nozzles at Melfort in 1998), each with two products (glyphosate and glufosinate ammonium):

a) **Conventional spray**: TeeJet XR8002, 100 L/ha @ 235 kPa (XR)
b) **TeeJet Air Induction:** 110015, 100 L/ha, 375 kPa (AI)
c) **Greenleaf TurboDrop:** 110015, 100 L/ha @ 405 kPa (TD)
d) **Greenleaf TurboDrop XL:** 110015 XL, 100 L/ha @ 365 kPa (TD-XL)
e) **Air Bubble Jet:** 110015, 100 L/ha, 470 kPa (ABJ)
f) **SprayMaster Raindrop Ultra:** 110015, 100 L/ha, 510 kPa (SM Ultra)
g) **Lechler ID:** 110015, 100 L/ha, 440 kPa (Lechler ID)
h) **Lurmark Ultra Lo-Drift:** 110015, 100 L/ha, 425 kPa (Lurmark ULD)
i) **Sprays International:** 110015, 100 L/ha, 425 kPa (Sprays Int'l)

Herbicides were be applied at 2 rates. For glyphosate, rates were 440 g ai/ha and 220 g ai/ha. For glufosinate-ammonium, rates were 500 g ai/ha and 250 g ai/ha. Each application was made at 100 L/ha. Pressures were varied slightly among treatments so that the flow rate was identical in all cases, and a constant travel speed could be maintained. To achieve 100 L/ha, the venturi tips were one size smaller than the standard nozzle, but operated at a higher pressure, in accordance with recommended procedure. Boom height was 50 cm above the target in all cases.

Experiment 3. Low-Drift Adjuvants.

Two low-drift adjuvants were compared using two rates of glyphosate. Adjuvants were observed to reduce spray pattern uniformity with conventional flat fan nozzles (Experiment 1). This effect could be eliminated through a lower adjuvant rate and use of a TurboTeeJet nozzle:

a) **Conventional spray (no adjuvant):** XR11002, 100 L/ha @ 250 kPa (XR11002)
b) **Low-drift nozzle (no adjuvant):** TT11002, 100 L/ha @ 275 kPa (TT11002)
c) **Low-drift nozzle & DR2000 @ 0.5 g/L:** TT11002, 100 L/ha @ 275 kPa (TT & DR)
d) **Low-drift nozzle & Array @ 8.9 g/L:** TT11002, 100 L/ha @ 275 kPa (TT & AR)

As with Experiment 2, herbicides were be applied at 2 rates. For glyphosate, rates were 440 g ai/ha and 220 g ai/ha. For glufosinate-ammonium, rates were 500 g ai/ha and 250 g ai/ha. Each application was made at 100 L/ha. Pressures were varied slightly among treatments so that the flow rate was identical in all cases, and a constant travel speed could be maintained.

Plot preparation

This research project was carried out at the Agriculture and Agri-Food Canada research farm in Saskatoon, SK, and at the Melfort Research Farm in the summer of 1998. Uniform and level field sites were selected for the study. Each block was divided into three parallel strips throughout its length: buckwheat alone, tame oats alone, and oriental mustard alone (Figure 1). Weed control in each plot was assessed without crop competition on simulated species.

Weed Establishment

In all trials, simulated weeds were seeded using a 3.6 m wide Conserva-Pak drill with 30 cm row spacing. An N-P-K-S fertilizer blend was side-banded at seeding to assist in plant establishment. One drill pass was made with each simulated weed along the length of each block. Commercial varieties of tame buckwheat, oriental mustard and oats were seeded at rates of 40, 7 and 20 kg/ha, respectively. Each plot, when viewed in the direction of spraying, was comprised of 3.6 m of buckwheat, 3.6 m of mustard, and 3.6 m oats. Seeding was conducted during May for all trials.

Spray Application

All trials were conducted with a 5-nozzle 3-point hitch sprayer attached to a Ford 3910 tractor. Nozzle height was maintained at 50 cm above the targets for all treatments. Travel speeds were typically about 9 km/h, but varied slightly depending on the nozzle flow rate for Experiment 1. For Experiments 2 and 3, tractor speeds were kept constant and spray pressure was adjusted to obtain equivalent nozzle flow rates. Spray application was conducted at the 3-4 leaf stage.

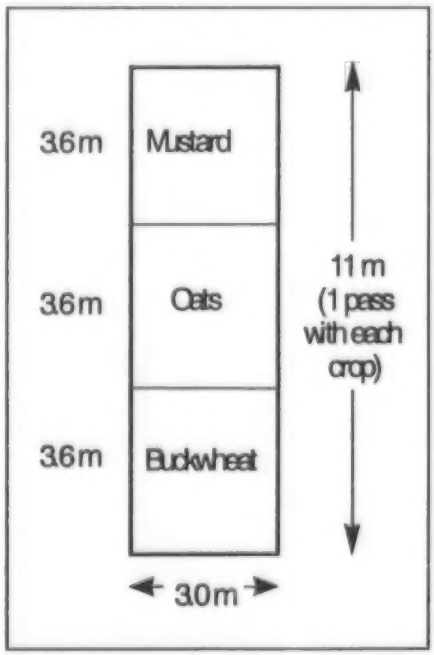

Figure 1: Plot layout for the 1997 trials

Sampling Procedure

Herbicide performance was assessed by visual ratings and biomass sampling when treatment differences became apparent, about 3 weeks after spray application. Four 1.5 m lengths of plant row were clipped at ground level in each plot. Samples were collected and placed in paper bags, and dried at 80 °C for 24 – 48 h. Bag contents were weighed, and dry weights were converted to g/m^2. For Experiment 1 in 1997, only visual control ratings were reported.

Experimental Design

Experiment 1: Treatments were assigned in a factorial arrangement (5 delivery methods * 4 rates, plus an untreated control). Plots were laid out in a split plot design, with rates as main plots. Treatments were replicated 4 times for each herbicide.

Experiment 2: Treatments were assigned in a factorial arrangement (9 nozzles * 2 rates, plus an untreated control) (8 nozzles at Melfort in 1998). Plots were laid out in a split plot design, with rates as main plots. Treatments were replicated 4 times for each herbicide.

Experiment 3: Treatments were assigned in a factorial arrangement (4 application methods * 2 rates, plus an untreated control). Plots were laid out in a split plot design, with rates as main plots. Treatments were replicated 4 times for each herbicide.

Data Analysis

All data were initially subject to analysis of variance (ANOVA) to identify significant treatment effects. When a relationship between the mean and standard deviation was detected, data were log or square-root transformed prior to ANOVA. Subsequent analysis depended on the experiment. For Experiment 1, non-linear regression of weed dry weight against herbicide rate was conducted using a logistic equation (Seefeldt et al. 1995):

$$\text{Weed dry weight} = C + \frac{D - C}{1 + \left(rate / GR_{50} \right)^{b}} \qquad [1]$$

where C = lower asymptote

D = upper asymptote

b = slope of inflection point

GR_{50} = the rate at which 50% of the effect is realized.

To standardize results, C and D were fixed at the mean value for the treatments to be compared, i.e., D was fixed at the mean control dry weight, and C was the mean dry weight at the highest herbicide rate. This was done so that all application systems were compared over the same response range. Comparisons of GR_{50} values were done with the standard error of the estimate.

For Experiments 2 and 3, differences between weed dry weight means were determined through comparison to other means and their associated standard errors, and depicted graphically.

Spray Retention Experiments.

Spray retention studies were conducted for Experiments 1 and 2 to determine whether any observed changes in herbicide efficacy were related to the amount of spray reaching the target plant. These studies were carried out in a new track room facility recently established at Agriculture & Agri-Food Canada. The track room measures 5 m x 15 m , and is capable of simulating a field plot sprayer in boom width (2.5 m, or 5 nozzles at 50 cm spacing), travel speed (up to 25 km/h) and spray pressure (up to 80 psi).

Plant Establishment: Tame buckwheat, oriental mustard, and tame oats were seeded separately in plastic cones (2.5 cm diameter, 16 cm depth). Plantings were watered as needed to ensure germination and seedling establishment. Stands were thinned to 1 plant per cone grown to the 3-leaf stage.

Spray Application and Sample Collection: The track room sprayer was equipped with the identical nozzles, and operated at the same pressures and speeds as for the field experiments. Two plants of each species were placed in the area to be sprayed, one under the nozzle overlap, another under the centre of the nozzle (Figure 2). Additionally, a 15-cm petri plate was placed in line with each plant location to measure actual spray delivery. A tracer dye (Rhodamine WT) was added to the spray mixture at 0.1% (v/v) to permit deposit quantification. Four replicate sprays were applied for each treatment. Immediately after spraying, plants were removed from

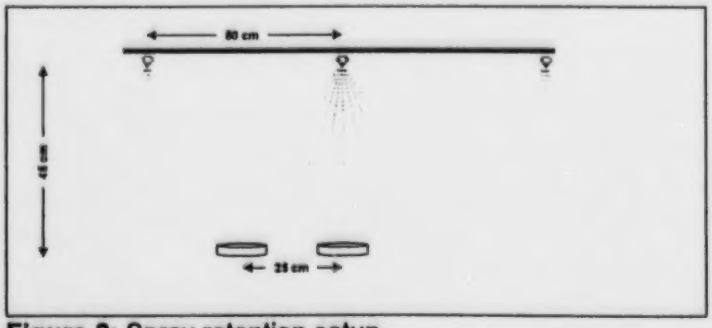

Figure 2: Spray retention setup.

the track room, clipped at soil level, and agitated in 100 mL 95% ethanol for 1 minute. Dye recovery using this method was > 95%, determined separately. A 20 mL subsample of the wash solution transferred to a glass jar, sealed, and stored in the dark awaiting analysis. Dye deposits were also washed from each petri-dish by triple rinsing with 95% ethanol. Within 12 h, dye concentrations were quantified using a Model RF-1501 spectrofluorometer equipped with Model ASC-5 auto-sampler (Shimadzu Instruments, Inc., Columbia MD). Dye content was calculated using standard curves. After washing, plants were placed in a paper bag oven-dried at 80 °C for 24-48 h, and weighed. Spray retention was expressed as µL of spray per g plant dry weight, adjusted for spray delivery determined from the petri-dish data. The adjustment for spray delivery normalized results so that all spray retention amounts were based on delivery of 100 L/ha. For example, a spray was not penalized or rewarded for delivering less or more spray to the target area than another nozzle.

The following data were calculated:

(a) Total spray delivery to petri plates (L/ha),

(b) Spray retention by each target plant (µL/g dry weight),

(c) The coefficient of variation (CV) of plant spray deposits (CV = standard deviation / mean*100),

(d) The ratio between spray retention and deposit CV (i.e., b/c). The rationale for this calculation was total amount deposited on target (more is better) and uniformity of deposit (lower CV is better) are both deemed important in spray delivery. Higher ratios identify treatments which are best able to meet both of these goals simultaneously.

Observations

General Observations on Nozzle Performance

Experiment 1: All atomization systems performed satisfactorily under field conditions. The XR8002 tips, the standard treatment, generated a uniform spray pattern with a "Medium" quality spray.

The TT11002 tips provided a very wide angle spray (150°) whose pattern provided large overlaps with adjacent nozzles. Spray quality was "Medium", although sprays were somewhat coarser than the XR tip.

The TurboDrop tip provided a "Very Coarse" spray in a uniform pattern comprising approximately an 80° spray angle. The venturi design was housed in a longer nozzle body than the other tips, necessitating a slight boom height adjustment. The air inlet to the nozzles remained free of plugs. This nozzle was operated at a slightly higher pressure than the other tips, as per manufacturer's suggestions.

The AirJet Nozzle required compressed air to operate, which was supplied with an on-board air compressor. Air was plumbed to an inlet at each nozzle. By adjusting the air and liquid pressures to the nozzle, a range of spray volumes and qualities could be obtained with the same tip. A combination of 70 kPa air and 180 kPa liquid resulted in a "Very Coarse" spray quality at the same flow rate as the other tips. Spray patterns were acceptable with this system.

The low-drift adjuvant (DR2000) was difficult to mix with the spray mixture, and care had to be taken to prevent clumping. The adjuvant narrowed the fan angle of the spray, modifying the pattern. This occasionally manifested itself in some streaking in the plots. Spray quality of the XR nozzle became "Coarse" with the addition of this adjuvant.

Experiment 2: All nozzles performed satisfactorily under field conditions. Liquid output rates varied among nozzles, necessitating pressure adjustments to standardize flow rates across treatments. The venturi-type nozzles as a group generated a much coarser spray than the standard nozzle (typically a "Very Coarse" spray), even at elevated pressures, although there were some differences among nozzles. The finest sprays among venturi nozzles were generated by the Air Bubble Jet and Lurmark Ultra Lo-Drift nozzles. The coarsest spray was generated by the SprayMaster Raindrop Ultra. The remaining nozzles were intermediate in their spray coarseness. Spray pattern fan angles also varied among tips. The widest fan angles (100°) were generated by the Lurmark ULD, the TeeJet AI, and the TurboDrop XL. The narrowest fan angles (70°) were generated by the Lechler ID and Sprays International nozzles. The remaining tips provided intermediate (80°) fan angles.

Experiment 3: The addition of DR2000 and Array narrowed spray fan angles somewhat, although not as dramatically as had been observed in Experiment 1. Reasons for better patterns are two-fold: first, a lower rate of DR2000 adjuvant was used in this experiment (0.5 g/L in Expt. 3 vs. 1 g/L in Expt. 1). Second, atomization of adjuvant through the TurboTeeJet nozzle resulted in reduced pattern collapse compared to a standard flat fan nozzle. Spray patterns were acceptable in all cases. Array did not produce as coarse a spray as DR2000, and it has been shown that the addition of ammonium sulphate ameliorates some of the spray

thickening effects of this DR2000. Ammonium sulphate has also been shown to increase glyphosate efficacy, notably when water hardness (presence of Ca^{++} and Mg^{++} ions) is an issue.

Experiment 1: Effect of Atomization Method on Weed Control

Weed control was generally satisfactory for both glufosinate-ammonium and glyphosate on buckwheat, mustard, and oats at the highest (recommended) herbicide rates. Symptoms from glufosinate-ammonium application appeared the day after spraying, and weed control was apparent soon after treatments were applied. Glyphosate symptoms developed within one week after spraying. Plant re-growth in the glufosinate-ammonium plots may have masked some treatment differences that were observable a few days after spraying, but became less apparent a few weeks later. Glyphosate control tended to be maintained over a longer time frame, and treatment differences may have been more observable for that reason.

Glufosinate-ammonium: Increased herbicide rates significantly improved weed control for all weeds in all years (Table 1 to Table 3). Typical dose responses for 1998 and 1999 are shown in Figure 3. Dose response analysis showed that glufosinate-ammonium was most efficacious on buckwheat in 1999 (mean GR_{50} values of 63 g/ha), and least effective on oats (mean GR_{50} values of 243 g/ha, Table 20). In 1998 and 1997, differences between weed species were not as apparent, with GR_{50} values of 159 g/ha (mustard) to 209 g/ha (oats) in 1998, and about 110 g/ha for both mustard and oats in 1997 (Table 21 and Table 22). All five application systems provided statistically similar control of all weeds in all years (Table 1 to Table 3). Non-linear dose response showed some differences in the effectiveness of application methods in some cases, but these were not very pronounced and somewhat inconsistent from year to year. For example, the TurboDrop nozzle had significantly lower buckwheat control in 1998, but performed as well as the other systems in other years and on other weeds. At the recommended herbicide rate, these treatment differences were not detectable.

Glyphosate: As with Glufosinate-ammonium, herbicide rate had a pronounced impact on weed control in all years on all weeds (Table 4 to Table 6). At rates below the recommended rate, weed control diminished gradually at first, with similar weed control at half the recommended rate in many cases (Figure 4). All weed species had similar GR_{50} values in 1998 (75 g/ha to 86 g/ha, Table 21). In 1997, oats were much easier to control than mustard (GR_{50} values of 54 g/ha vs. 107 g/ha), whereas in 1999, oats was more difficult to control (147 g/ha GR_{50} for oats vs. about 115 g/ha for buckwheat and mustard, Table 20 and Table 22).

Differences between the five application systems could be identified in most years even though all systems provided acceptable weed control at the recommended rates. In 1997 and 1999, DR2000 significantly improved oat control over the other treatments. The AirJet reduced oat control in 1997 and 1998, but otherwise performed as well as the standard nozzle. The Turbo TeeJet had reduced buckwheat control in 1998, and DR2000 had poor mustard control that same year. Reduced performance of the TT nozzle is difficult to explain in light of its otherwise good performance. Loss of weed control with DR2000 could be attributed to poor spray patterns caused by the thickening of the spray, which collapsed patterns and provided improper overlap at the 50 cm boom height. Adjuvant use will be explored in more detail in Experiment 3.

Experiment 2: Venturi Nozzle Comparison

Weed control was generally satisfactory for both glufosinate-ammonium and glyphosate on buckwheat, mustard, and oats at the highest (recommended) herbicide rates. As in Experiment 1, glyphosate provided higher weed control than glufosinate-ammonium.

Glufosinate-ammonium: Herbicide rate had a significant impact on weed dry weight in all years, locations, and weeds (Table 7 to Table 10). As expected, higher herbicide rates always resulted in better weed control. Nozzles provided statistically similar control of all weeds in 1998 and 1999, except for mustard in Melfort in 1999. In this case, the TurboDrop nozzle had somewhat greater mustard dry weight than the standard nozzle (Figure 5). This was not reflected in visual weed control ratings, however, and may have been due to sampling variability in dry weight samples. Weed control ratings for Melfort in 1998 suggested that the SprayMaster Ultra performed slightly less well than other nozzles in oat control. This did not recur in 1999, possibly due to the use of a new model of the Ultra nozzle.

Glyphosate: Herbicide rate did not affect weed control as frequently for glyphosate as it had for glufosinate-ammonium. In 33% of cases, half the herbicide rate provided as much weed control as the full rate (Table 11 to Table 14). In four of a possible 12 cases (i.e, location – weed combinations), nozzle type had a significant impact on weed dry weight. At Melfort in 1998, the TD and SM Ultra nozzles had higher buckwheat dry weights than the XR nozzle (Figure 6). In 1999, The TD-XL nozzle had higher mustard dry weights than the remaining nozzles (Figure 7), and both the TD-XL and SM Ultra had higher oat dry weights (Figure 8). At Saskatoon in 1999, an interaction between nozzle type and herbicide rate was found – at the high herbicide rate, no differences between nozzles occurred (Figure 9). At the low rate, the venturi nozzles as a group had higher dry weights than the XR nozzle.

Experiment 3: Low-Drift Adjuvants

Weed control was generally very good in this trial. Relatively few differences occurred between treatments. Herbicide rate had a significant impact in 7 of 8 cases (Table 15 to Table 17). Nozzle – Adjuvant combinations had a significant impact in only one case: in 1998, buckwheat dry weight was highest without the low-drift adjuvants, and lower with the addition of either DR2000 or Array (Figure 10). Although not statistically significant, the Array treatment also tended to improve glyphosate effectiveness on buckwheat in 1999, and DR2000 improved effectiveness on oats (Figure 11). This illustrates that these adjuvants may have the ability to improve glyphosate activity on a difficult-to-control weed such as buckwheat.

Spray Retention Experiments

Experiment 1: The amount of spray retained by plants depended on species. The broadleaf species, buckwheat and mustard, typically retained 250 to 300 µL of spray per g plant dry weight (Figure 12). Oats retained less than 1/3 this amount, about 75 µL/g. This is likely due to a combination of leaf orientation and wettability – the broadleaf species tested have mostly horizontally oriented leaves with easy-to-wet surfaces, whereas oat plants have smaller, more vertically orientated leaves with difficult-to-wet surfaces. The difficult nature of the oat targets is also revealed in the overall variability of spray deposits: the CV for oat spray deposits was about 50% averaged over all treatments, whereas it was about 20% for the broadleaf species (Figure 13).

Overall spray delivery to the petri plates depended on application system (Table 18). Spray delivery averaged between 85 and 90 L/ha for the XR and TT nozzles, and averaged about 95 to 105 L/ha for the coarser sprays (TD, AJ, and DR2000, Figure 14). This reflects the increased ability of a coarser spray to be delivered directly beneath the nozzle, whereas the finer sprays were displaced more from their intended flight path through boom movement-induced air turbulence. This aspect was reflected to some degree in the measure of variability in the deposit CVs. The XR nozzle had a deposit CV of 18%, whereas the other nozzles fluctuated between 8 and 13% (Figure 15). The TT nozzle, with its multiple-overlap pattern, had the lowest CV, at 8%.

Spray retention did not differ significantly among nozzles for buckwheat or mustard, but had a significant effect for oats (Table 18, Figure 16 to Figure 18). In oats, the AirJet nozzle had lower retention values than the other nozzles (Figure 18). This is likely related to the coarseness of the spray – it was very difficult to exactly replicate the air pressures between the lab and field, and a coarser spray was necessarily produced under the lab conditions than had

been produced for the field trials. This increase in coarseness had no effect on broadleaf spray retention, suggesting that broadleaf plants are well suited to intercepting and retaining coarse sprays.

Calculation of the ratio between deposit amount and deposit CV showed that low-drift spays obtained a good compromise between deposit amount and uniformity on broadleaf weeds, typically exceeding that of the XR nozzle for buckwheat, and being similar for mustard (Figure 19). In particular the TD nozzle had a high ratio for mustard. Ratios were much lower for oats than they were for the broadleaf species. Coarser sprays were at a disadvantage to the XR nozzle for obtaining good deposits on oats. The sprays that obtained equivalent deposit amounts to the XR, i.e., TD and DR2000, were penalized by more variable deposits. The AirJet obtained good deposit uniformity, but had overall lower deposits. These results suggest that performance differences with coarser sprays are more likely to appear in grassy weeds, where good deposit quality is difficult to achieve.

Experiment 2: As for Experiment 1, spray retention amounts varied with species, with broadleaf species retaining approximately 4 times the amount of oats per gram dry weight (Figure 20). Spray deposit CVs were higher overall compared to Experiment 1, being 24% for buckwheat and 41 and 49% for mustard and oats, respectively (Figure 21). Petri plate deposits were significantly affected by nozzle (Table 19), and showed a similar trend to Experiment 1: the XR nozzle had lower deposits (85L/ha) than the venturi nozzles (90 to 105 L/ha, Figure 22). Once again, it was likely the coarser nature of the venturi sprays that prevented turbulent displacement of the spray. The deposit CV ranged between 11 and 20% for all sprays (Figure 23). The most uniform deposit was achieved with the Lurmark ULD, the most variable deposit occurred with the Lechler ID. These deposit CVs are typical of field application variabilities, and are considered acceptable.

Buckwheat, mustard, and oats were not statistically affected by application method (Table 19, Figure 24 to Figure 26). This suggests that all nozzles were equally well suited to delivering the required herbicide dosage to the target weeds, in spite of obvious differences in spray quality. The lack of statistically different retention on oats is surprising, given that in the field, performance differences were often observed on oats. Although the inherently greater variability of deposits on oats prevented statistically significant differences from being detected, this variability likely detracted from the biological performance of the coarser sprays, as discussed earlier. This aspect requires further investigation.

Relating Field Efficacy to Lab Spray Retention

The retention experiments showed that in the majority of cases, no statistical differences in spray retention among various atomization systems could be detected. The sole exception was with the AirJet nozzle on oats, where a wrong adjustment of spray quality, leading to a coarser spray than had been used in the field, was suspected. In Experiment 1 field results, glufosinate-ammonium efficacy was significantly impacted by application method in 1 of a possible 8 cases (13% of the time), whereas glyphosate efficacy was affected 6 of 8 times (75% of the time). In Experiment 2 field results, glufosinate-ammonium efficacy was significantly affected by nozzle choice in 8% of cases, whereas glyphosate efficacy was significantly affected by nozzle choice 33% of the time. It would appear that the impact of application method depends to a degree on the herbicide in question, and retention studies appear unable to predict such impacts. Other variables that were not measured must therefore play a role in herbicide performance.

A possible reason for the lack of agreement in spray retention and herbicide efficacy data for different herbicides lies in the measurement methodology. Although weed control with glyphosate was typically superior to glufosinate-ammonium, glyphosate also appeared in these tests to be more sensitive to application method. This observation must be interpreted carefully: because weed control with glyphosate was typically near 100% at the high herbicide rate, a small reduction in weed control manifested itself in a statistically significant manner even if weed control remained above 90%. Thus a statistically significant response of application method rarely translated into a reduction in weed control below commercially acceptable levels. For glufosinate-ammonium, overall weed control was lower, and variations in nozzle effectiveness were masked by the already higher weed biomass present in the plots. It was thus more difficult to detect statistically significant impacts of application method even though control may have been affected to a more detrimental degree. Therefore, the dose-response biomass sampling methodology employed in the present study was more likely to suggest a more effective herbicide as more sensitive to application parameters than a less effective one.

Conclusions

These experiments showed that low-drift atomization technologies have potential to reduce drift with only occasional and minor effects on product effectiveness. When significant effects of application method were noted, these resulted in small reductions in weed control and never resulted in product failure. Use of recommended herbicide rates, proper staging of the application, and use of 100 L/ha water volumes will ensure that low-drift sprays maintain

equivalent weed control performance to a standard flat fan nozzle with both glufosinate-ammonium and glyphosate.

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Acknowledgements

The technical assistance of Brian Caldwell, Kelly Byer, Ryan Pilsner, and Krista Connick was instrumental in completing this research. The assistance of Gaayana Raju, Jason Caldwell, Tyler Youngs, David Keegan, Warren Pilsner, Trent Duff, Reid Ledinski, and Ryan Crompton is much appreciated. Financial support was provided by the Saskatchewan Agricultural Development Fund, Monsanto Canada, Agriculture and Agri-Food Canada, and Health Canada. In-kind contributions were provided by Monsanto Canada, Aventis Canada, John Brooks Company, Greenleaf Technologies, Lechler GmbH, Federated Cooperatives, Delavan Spray Technologies, ABJ Agri-Products, Rosen's, and Rhodia.

Appendix 1: Tables

Table 1: Analysis of variance for weed control in 1997, glufosinate-ammonium, Experiment 1.

	Mustard		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	4.12*	0.010*	1.88	0.143
Nozzle	1.69	0.164	0.57	0.6882
Rate	223.60*	0.000*	306.56*	0.000*
Nozzle * Rate	0.96	0.498	0.47	0.926

Table 2: Analysis of variance for weed dry weight in 1998, glufosinate-ammonium, Experiment 1.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	21.50*	0.000*	18.10*	0.000*	2.28	0.089
Nozzle	2.09	0.094	0.26	0.901	1.51	0.211
Rate	109.43*	0.000*	20.57*	0.000*	40.43*	0.000*
Nozzle * Rate	1.08	0.392	0.66	0.786	0.58	0.848

Table 3: Analysis of variance for weed dry weight in 1999, glufosinate-ammonium, Experiment 1.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	11.67*	0.000*	14.58*	0.000*	30.31*	0.000*
Nozzle	1.31	0.279	1.36	0.260	1.59	0.189
Rate	33.48*	0.000*	32.41*	0.000*	86.63*	0.000*
Nozzle * Rate	0.75	0.697	0.41	0.954	0.98	0.480

Table 4: Analysis of variance for weed control in 1997, glyphosate, Experiment 1.

	Mustard		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	5.32*	0.003*	2.92*	0.042*
Nozzle	11.15*	0.000*	3.49*	0.013*
Rate	444.73*	0.000*	130.26*	0.000*
Nozzle * Rate	2.41*	0.013*	1.32	0.235

Table 5: Analysis of variance for weed dry weight in 1998, glyphosate, Experiment 1.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	11.04*	0.000*	18.07*	0.000*	1.52	0.220
Nozzle	2.79*	0.035*	3.16*	0.021*	4.49*	0.003*
Rate	51.40*	0.000*	88.62*	0.000*	157.39*	0.000*
Nozzle * Rate	2.18*	0.025*	0.55	0.875	1.95*	0.047*

Table 6: Analysis of variance for weed dry weight in 1999, glyphosate, Experiment 1.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	2.89*	0.043*	12.72*	0.000*	4.95*	0.004*
Nozzle	0.29	0.884	1.21	0.317	9.01*	0.000*
Rate	120.45*	0.000*	196.11*	0.000*	326.07*	0.000*
Nozzle * Rate	1.79	0.073	1.24	0.278	1.70	0.091

Table 7: Analysis of variance for weed dry weight in 1998 venturi nozzle comparison – glufosinate-ammonium, Melfort, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	6.13*	0.001*	4.55*	0.007*	6.65*	0.001*
Nozzle	1.28	0.282	0.84	0.561	2.15	0.057
Rate	12.03*	0.001*	6.25*	0.016*	10.44*	0.002*
*Nozzle * Rate*	0.22	0.979	0.77	0.619	1.11	0.373

Table 8: Analysis of variance for weed dry weight in 1998 venturi nozzle comparison – glufosinate-ammonium, Saskatoon, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	6.37*	0.001*	0.59	0.628	2.33	0.086
Nozzle	1.33	0.251	0.32	0.954	1.43	0.205
Rate	78.20*	0.000*	44.60*	0.000*	16.65*	0.000*
*Nozzle * Rate*	1.12	0.366	1.36	0.237	0.06	1.000

Table 9: Analysis of variance for weed dry weight in 1999 venturi nozzle comparison – glufosinate-ammonium, Melfort, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	1.60	0.202	0.72	0.545	10.73*	0.000*
Nozzle	1.76	0.107	2.87*	0.010*	0.93	0.497
Rate	11.90*	0.001*	28.31*	0.000*	8.81*	0.005*
*Nozzle * Rate*	1.42	0.209	1.91	0.078	0.31	0.959

Table 10: Analysis of variance for weed dry weight in 1999 venturi nozzle comparison – glufosinate-ammonium, Saskatoon, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	2.26	0.093	15.31*	0.000*	3.29*	0.028*
Nozzle	0.64	0.743	1.26	0.283	2.00	0.065
Rate	11.24*	0.002*	30.49*	0.000*	45.10*	0.000*
*Nozzle * Rate*	1.03	0.426	1.86	0.087	1.17	0.338

Table 11: Analysis of variance for weed dry weight in 1998 venturi nozzle comparison – glyphosate, Melfort, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	10.82*	0.000*	9.60*	0.000*	18.22*	0.000*
Nozzle	2.32*	0.041*	2.11	0.062	2.13	0.060
Rate	7.77*	0.008*	7.78*	0.008*	16.64*	0.000*
*Nozzle * Rate*	0.48	0.843	1.36	0.247	0.47	0.850

Table 12: Analysis of variance for weed dry weight in 1998 venturi nozzle comparison – glyphosate, Saskatoon, Experiment 2.

	Buckwheat		Mustard		Oats	
Effect	*F-Value*	*p-level*	*F-Value*	*p-level*	*F-Value*	*p-level*
Rep	4.90*	0.005*	7.29*	0.000*	7.73*	0.000*
Nozzle	1.22	0.309	1.48	0.187	1.43	0.205
Rate	37.46*	0.000*	2.23	0.142	0.33	0.571
*Nozzle * Rate*	1.52	0.175	0.84	0.571	0.40	0.917

Table 13: Analysis of variance for weed dry weight in 1999 venturi nozzle comparison – glyphosate, Melfort, Experiment 2.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	22.60*	0.000*	5.73*	0.002*	17.62*	0.000*
Nozzle	0.43	0.897	2.20*	0.042*	3.29*	0.004*
Rate	0.85	0.360	5.90*	0.019*	0.08	0.784
Nozzle * Rate	0.60	0.775	0.97	0.472	0.24	0.980

Table 14: Analysis of variance for weed dry weight in 1999 venturi nozzle comparison – glyphosate, Saskatoon, Experiment 2.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	1.48	0.231	2.21	0.098	4.31*	0.009*
Nozzle	1.09	0.388	0.74	0.653	2.12	0.050
Rate	39.48*	0.000*	25.67*	0.000*	166.74*	0.000*
Nozzle * Rate	1.28	0.277	0.80	0.603	2.28*	0.036*

Table 15: Analysis of variance for weed dry weight in 1997 low-drift adjuvant comparison – glyphosate, Experiment 3.

	Mustard		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	4.77*	0.006*	7.54*	0.000*
Nozzle	2.68	0.058	0.17	0.915
Rate	54.16*	0.000*	58.06*	0.000*
Nozzle * Rate	1.25	0.289	0.19	0.994

Table 16: Analysis of variance for weed dry weight in 1998 low-drift adjuvant comparison – glyphosate, Experiment 3.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	1.93	0.156	4.93*	0.010*	1.78	0.181
Nozzle	3.33*	0.039*	1.19	0.339	1.81	0.176
Rate	23.77*	0.000*	18.06*	0.000*	12.27*	0.002*
Nozzle * Rate	2.65	0.075	1.80	0.178	1.60	0.220

Table 17: Analysis of variance for weed dry weight in 1999 low-drift adjuvant comparison – glyphosate, Experiment 3.

	Buckwheat		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	2.18	0.120	3.24*	0.043*	0.91	0.454
Nozzle	1.08	0.378	1.55	0.232	1.80	0.178
Rate	12.47*	0.002*	2.78	0.110	4.58*	0.044*
Nozzle * Rate	0.63	0.607	0.42	0.743	1.55	0.231

Table 18: Analysis of variance for spray retention in Experiment 1.

	Petri Plates		*Buckwheat*		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	2.09	0.1554	0.30	0.822	1.97	0.1725	0.83	0.5043
Nozzle	23.84*	0.0000*	1.07	0.413	1.42	0.2852	17.47*	0.0001*

Table 19: Analysis of variance for spray retention in Experiment 2.

	Petri Plates		*Buckwheat*		*Mustard*		*Oats*	
Effect	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***	***F-Value***	***p-level***
Rep	1.35	0.2806	0.85	0.5691	1.48	0.2176	1.25	0.3164
Nozzle	3.17*	0.0134*	1.10	0.3691	1.59	0.2181	0.33	0.8028

Table 20: GR_{50} values (± standard errors) for Experiment 1, 1997.

Atomization System	GR_{50} Values (± Standard Error)			
	Glyphosate		Glufosinate-ammonium	
	Mustard	Oats	Mustard	Oats
XR8002	125 ± 12	40 ± 5	97 ± 3	107 ± 7
TT11002	112 ± 12	49 ± 2	106 ± 8	107 ± 7
TD110015	127 ± 13	54 ± 4	115 ± 12	119 ± 9
Air Jet	128 ± 19	84 ± 3	115 ± 4	112 ± 4
DR2000	44 ± 8	45 ± 2	115 ± 9	113 ± 9
Mean	107	54	110	112

Table 21: GR_{50} values (± standard errors) for Experiment 1, 1998.

Atomization System	GR_{50} Values (± Standard Error)					
	Glyphosate			Glufosinate-ammonium		
	Buckwheat	Mustard	Oats	Buckwheat	Mustard	Oats
XR8002	88 ± 25	70 ± 15	72 ± 23	166 ± 17	163 ± 26	209 ± 41
TT11002	113 ± 15	82 ± 6	63 ± 17	132 ± 21	129 ± 36	219 ± 40
TD110015	79 ± 12	63 ± 3	67 ± 17	217 ± 20	188 ± 54	202 ± 41
Air Jet	60 ± 5	76 ± 3	91 ± 5	166 ± 40	162 ± 81	261 ± 80
DR2000	90 ± 44	119 ± 10	83 ± 15	141 ± 17	155 ± 82	156 ± 99
Mean	86	82	75	164	159	209

Table 22: GR_{50} values (± standard errors) for Experiment 1, 1999.

Atomization System	GR_{50} Values (± Standard Error)					
	Glyphosate			Glufosinate-ammonium		
	Buckwheat	Mustard	Oats	Buckwheat	Mustard	Oats
XR8002	143 ± 6	120 ± 7	140 ± 8	61 ± 1	121 ± 20	231 ± 14
TT11002	104 ± 31	111 ± 6	148 ± 6	93 ± 10	116 ± 12	209 ± 30
TD110015	103 ± 14	130 ± 9	182 ± 11	71 ± 5	169 ± 50	232 ± 26
Air Jet	108 ± 2	112 ± 12	165 ± 18	51 ± 1	105 ± 16	287 ± 26
DR2000	108 ± 11	103 ± 2	101 ± 2	37 ± 5	159 ± 22	256 ± 29
Mean	113	115	147	63	134	243

Appendix 2: Figures

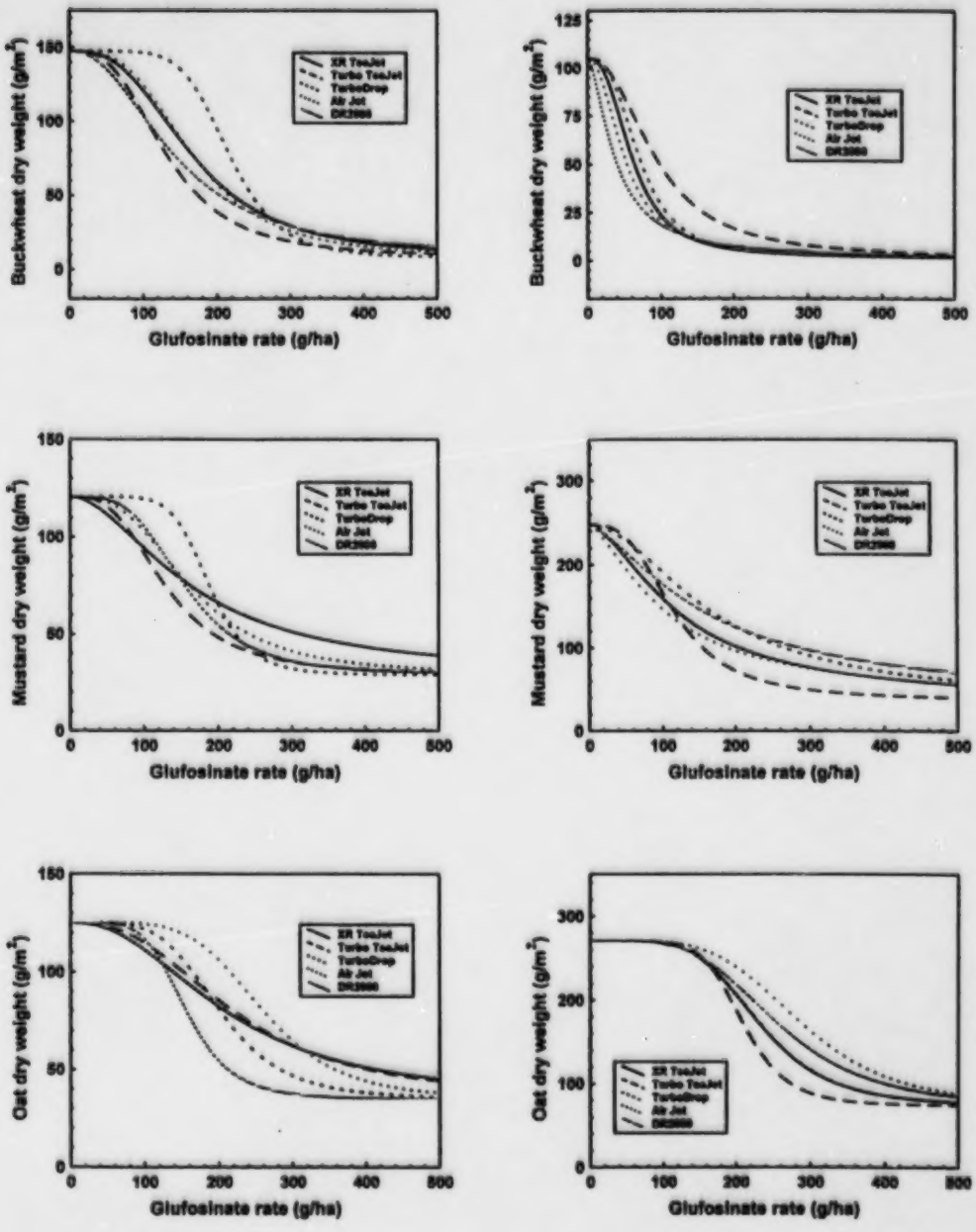

Figure 3: Dose response curves for three weeds in 1998 (left column) and 1999 (right column) for Experiment 1, glufosinate-ammonium.

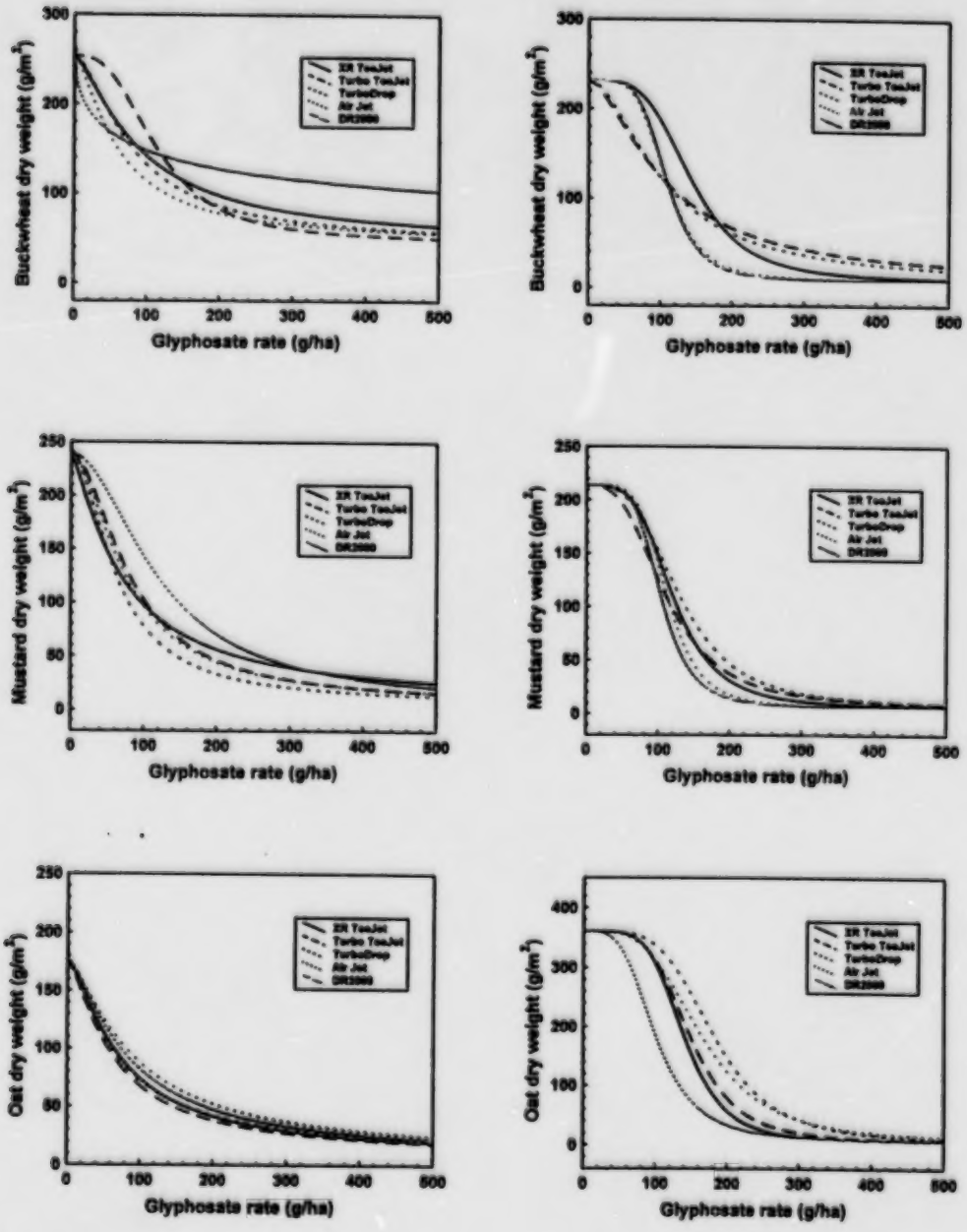

Figure 4: Dose response curves for three weeds in 1998 (left column) and 1999 (right column) for Experiment 1, glyphosate.

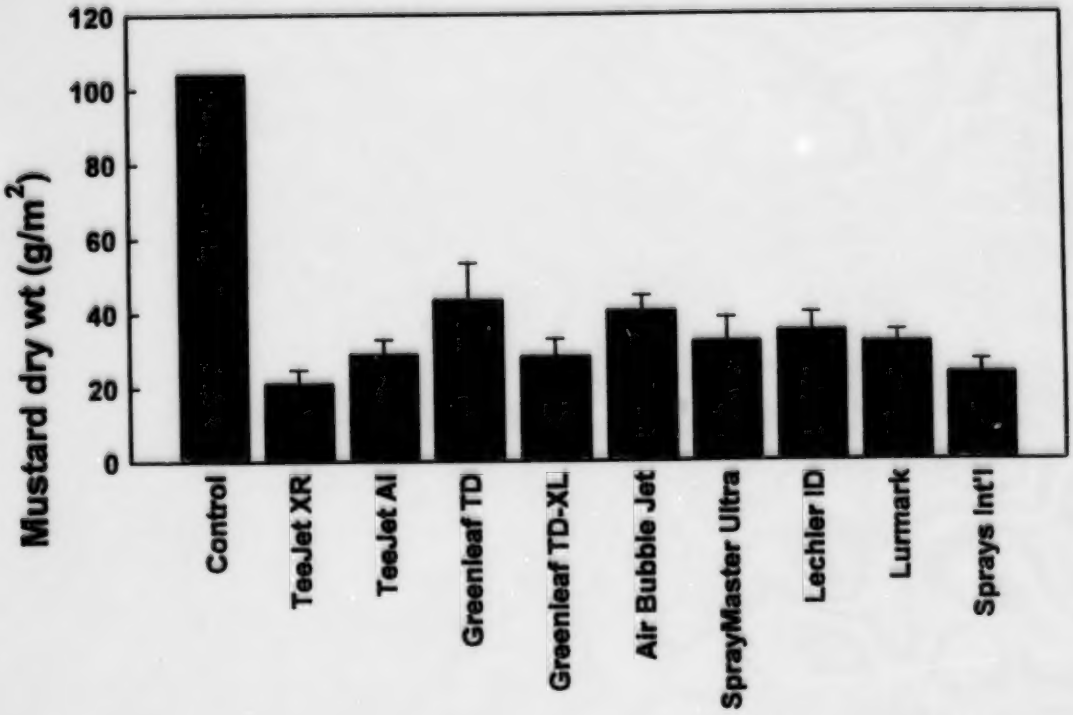

Figure 5: Mustard dry weight after application of glufosinate-ammonium with several venturi nozzles (Melfort, 1999).

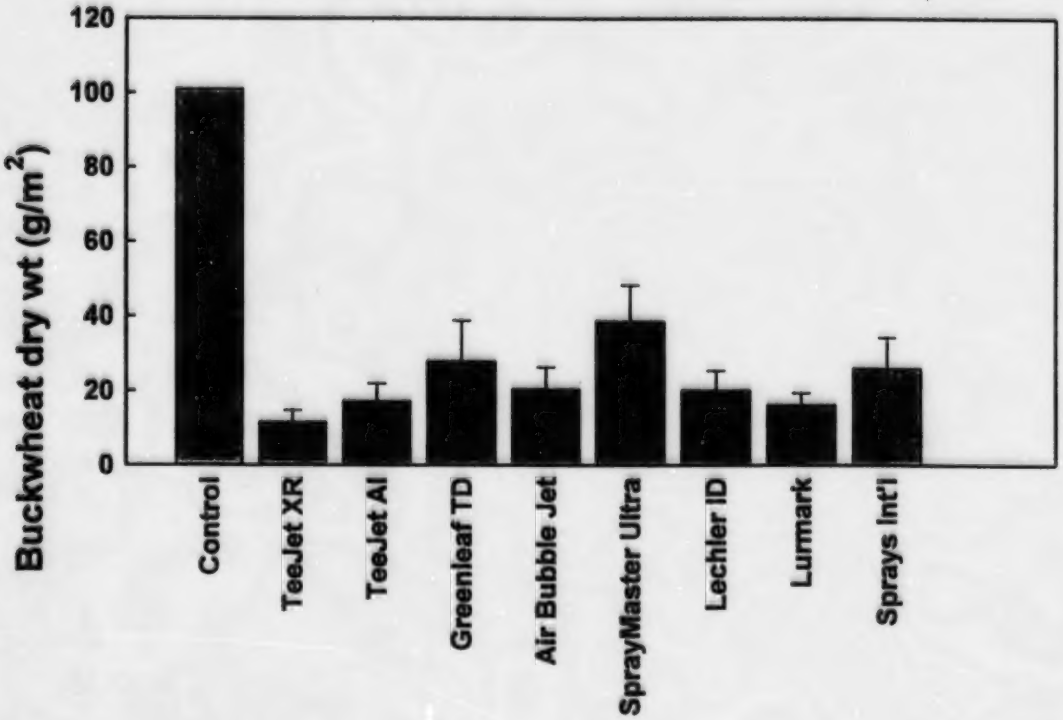

Figure 6: Buckwheat dry weight after application of glyphosate with several venturi nozzles (Melfort, 1998).

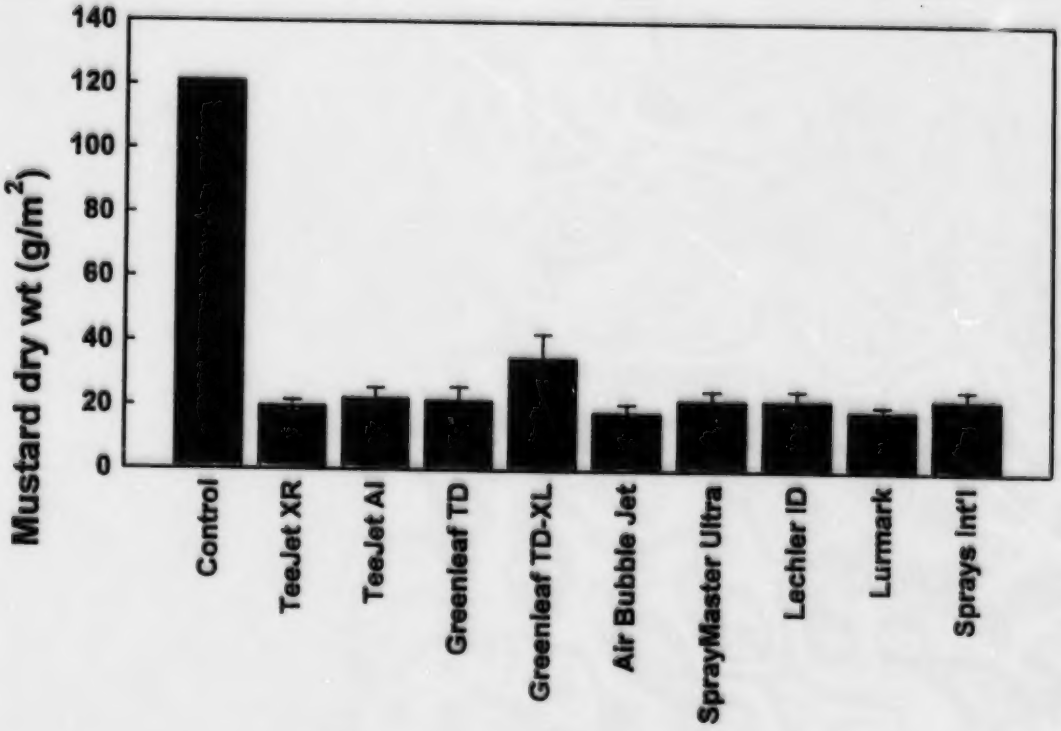

Figure 7: Mustard dry weight after application of glyphosate with several venturi nozzles (Melfort, 1999).

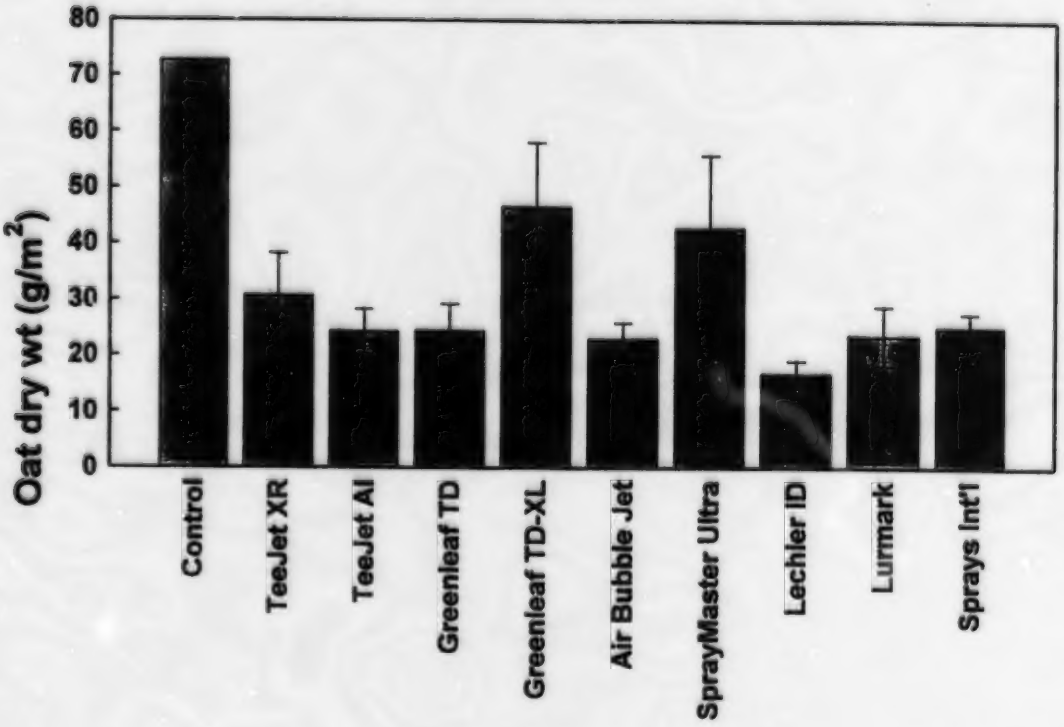

Figure 8: Oat dry weight after application of glyphosate with several venturi nozzles (Melfort, 1999).

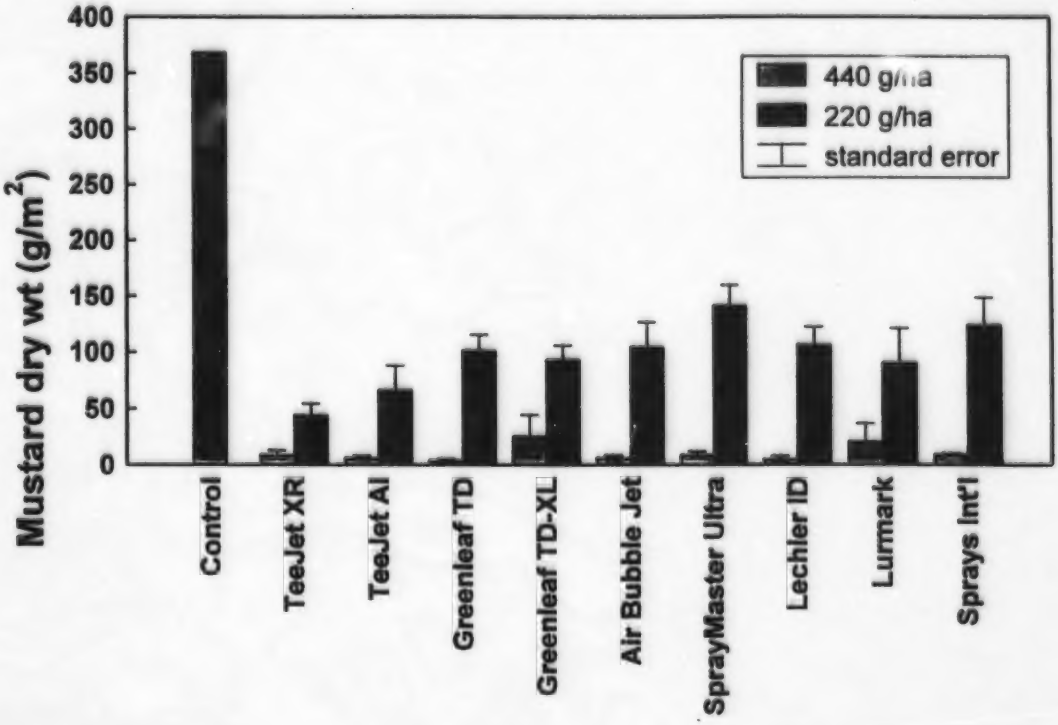

Figure 9: Oat dry weight after application of glyphosate at two rates with several venturi nozzles (Saskatoon, 1999).

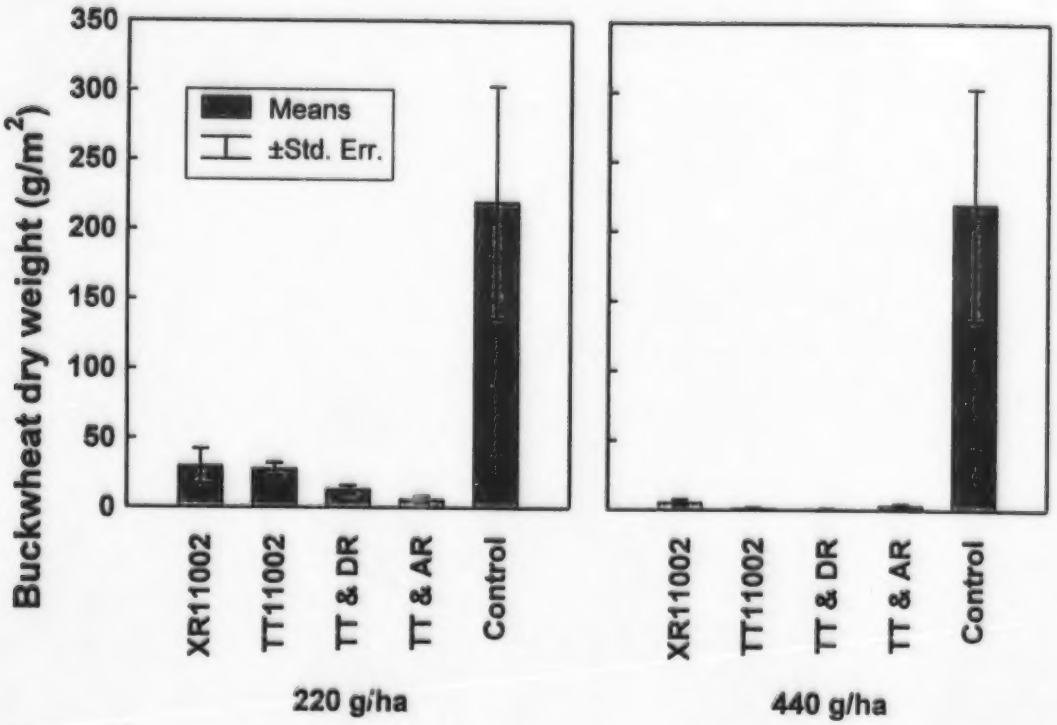

Figure 10: Buckwheat dry weight after application of glyphosate with and without low-drift adjuvants, 1998.

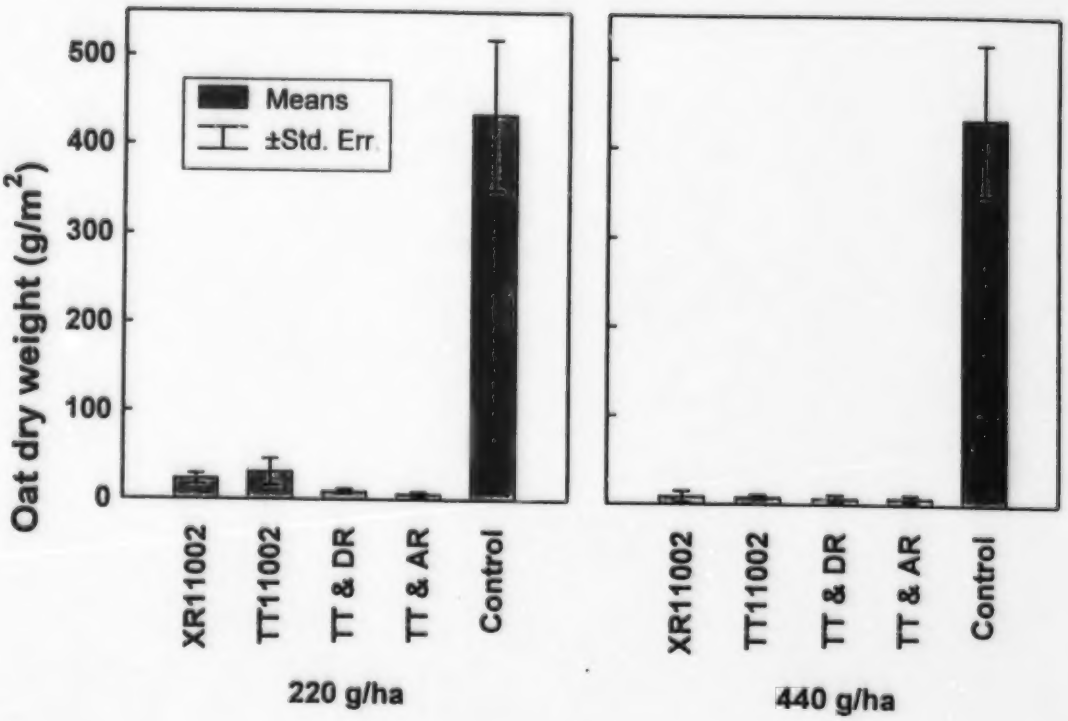

Figure 11: Oat dry weight after application of glyphosate with and without low-drift adjuvants, 1999.

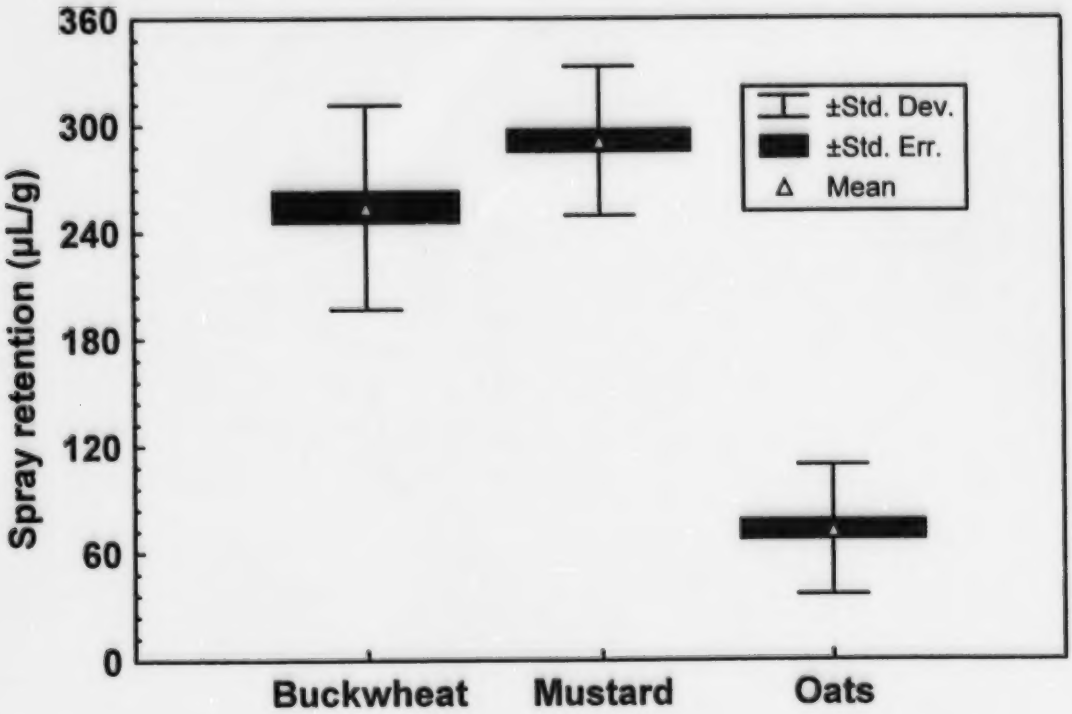

Figure 12: Mean spray retained by three simulated weeds in Retention Experiment 1.

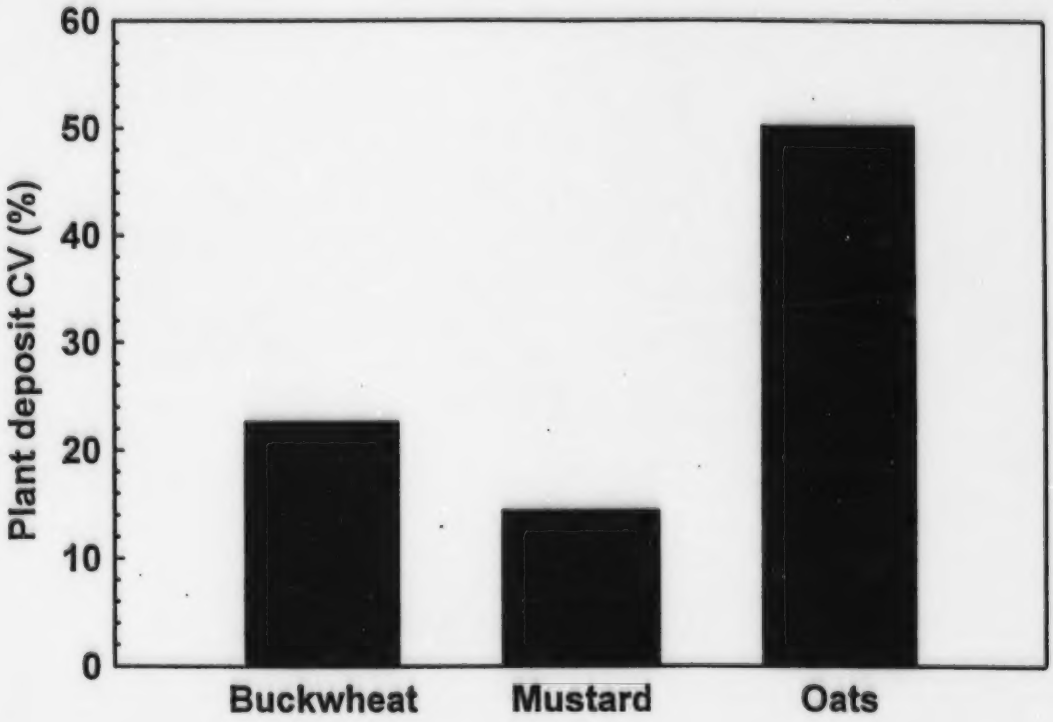

Figure 13: Spray deposit variability (as coefficient of variation, CV, with n=40) on three simulated weeds in Retention Experiment 1.

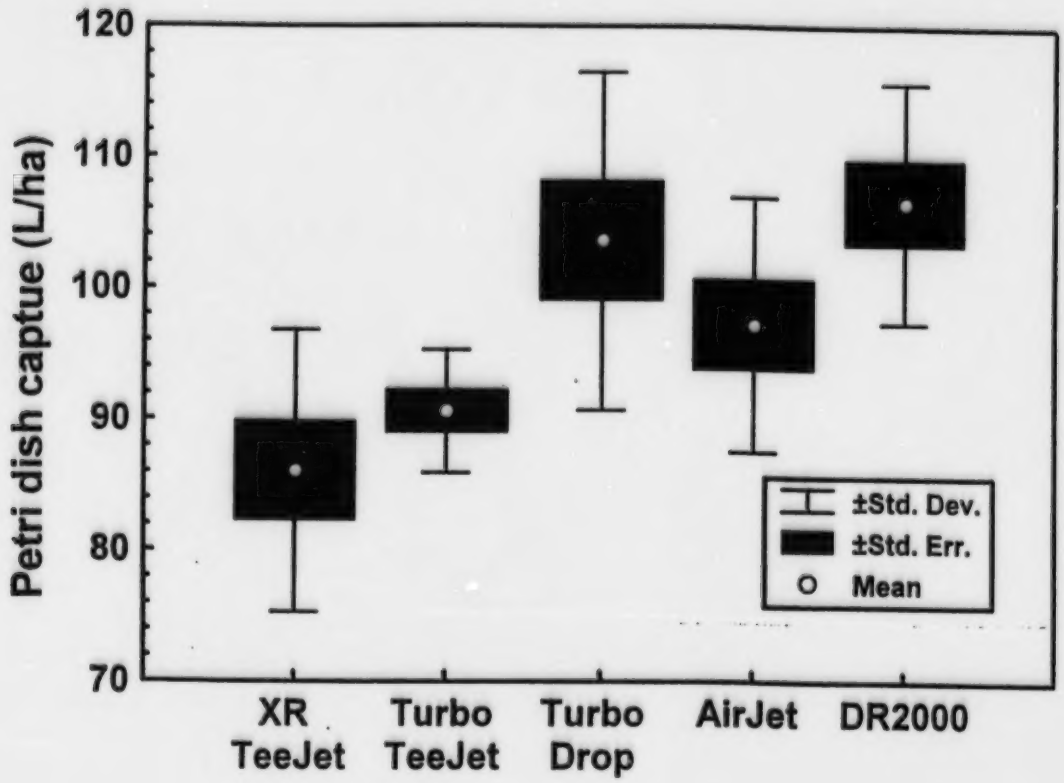

Figure 14: Mean spray delivery to petri plates in the spray swath for 5 atomization systems, Retention Experiment 1.

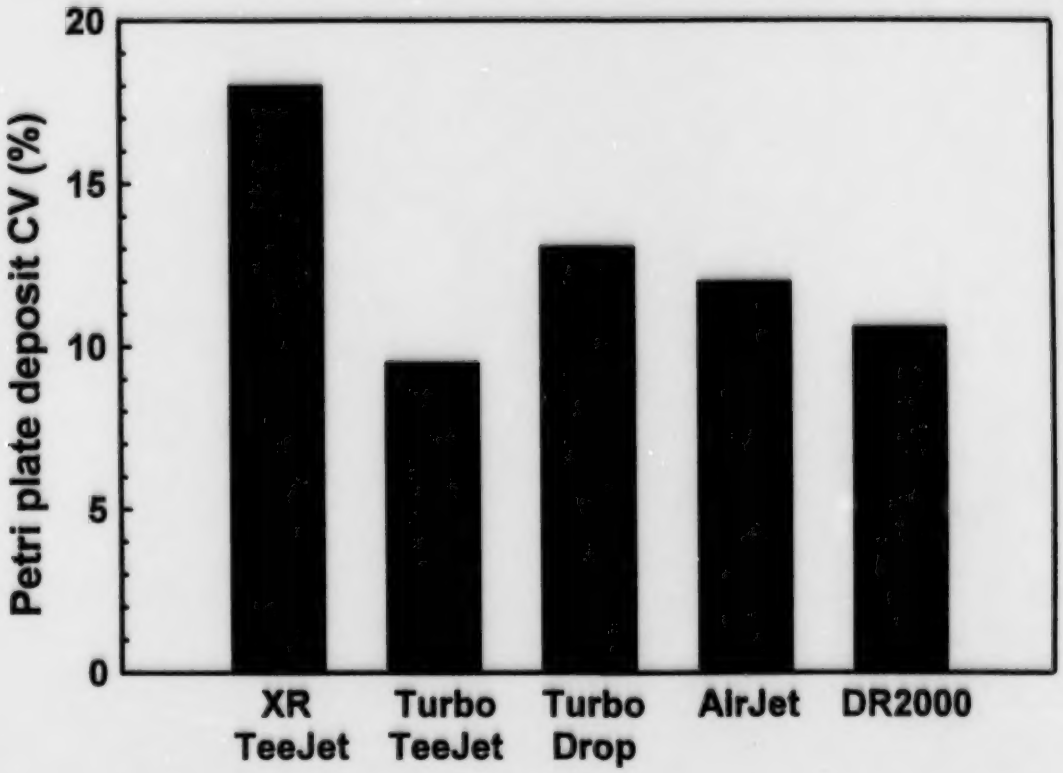

Figure 15: Spray deposit variability (as coefficient of variation, CV, with n=24) on petri plates in the spray swath for 5 atomization systems, Retention Experiment 1.

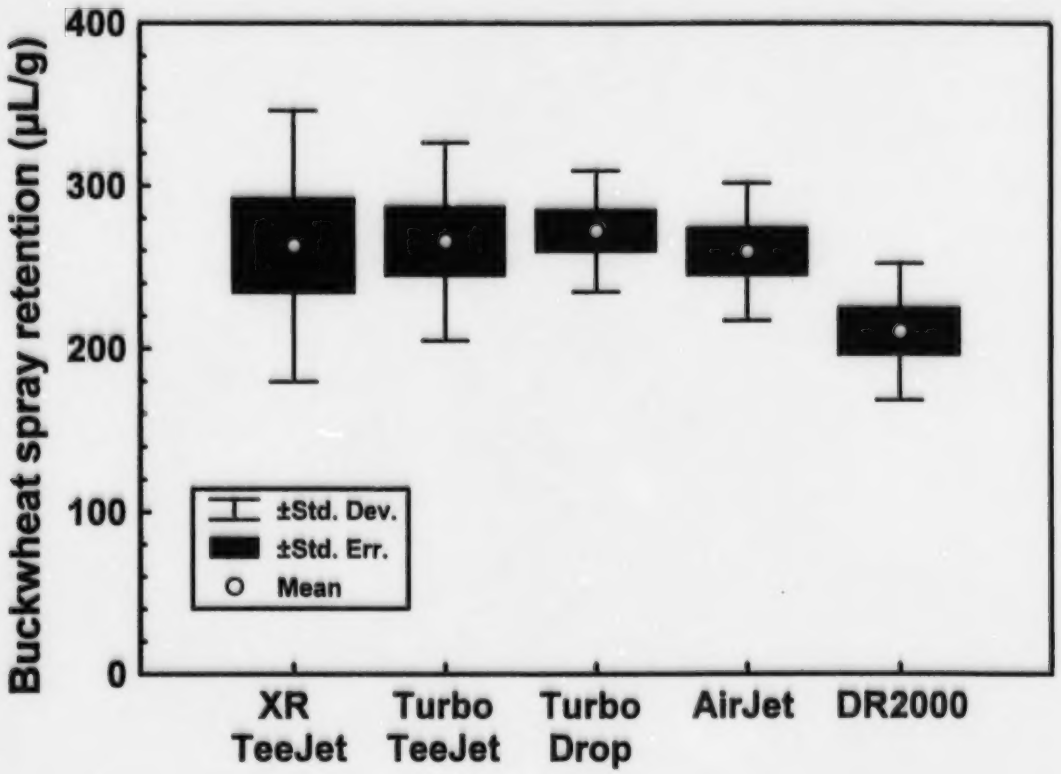

Figure 16: Mean spray retained by buckwheat from 5 atomization systems in Retention Experiment 1.

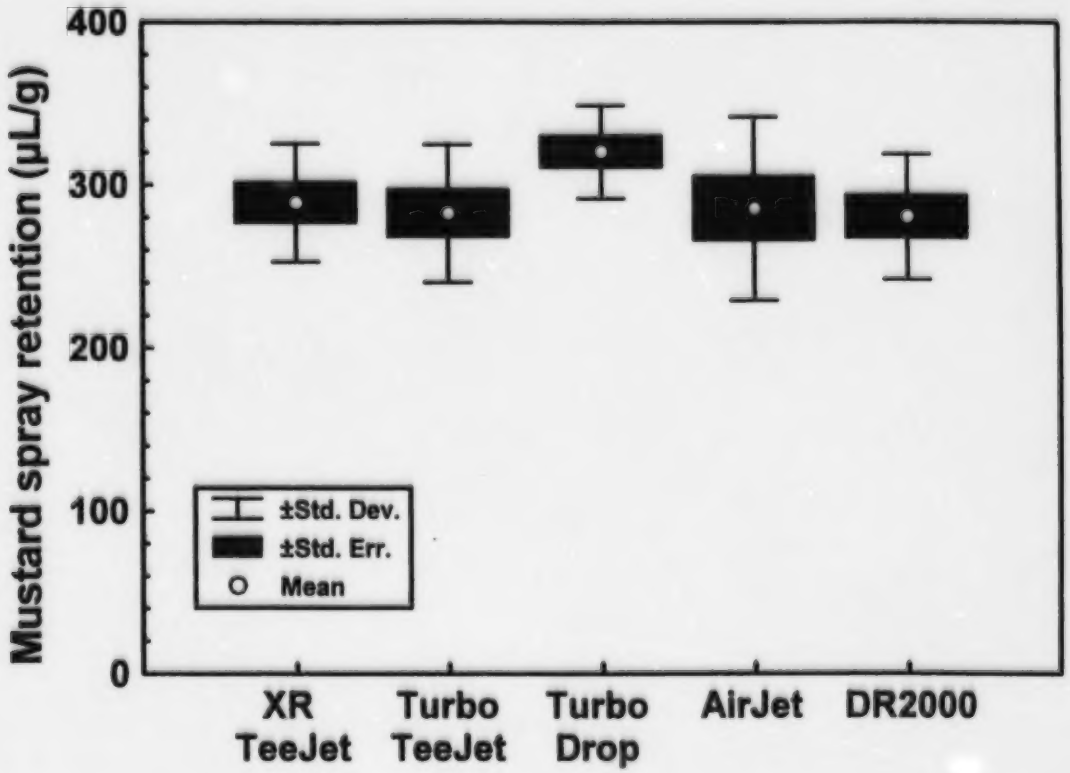

Figure 17: Mean spray retained by mustard from 5 atomization systems in Retention Experiment 1.

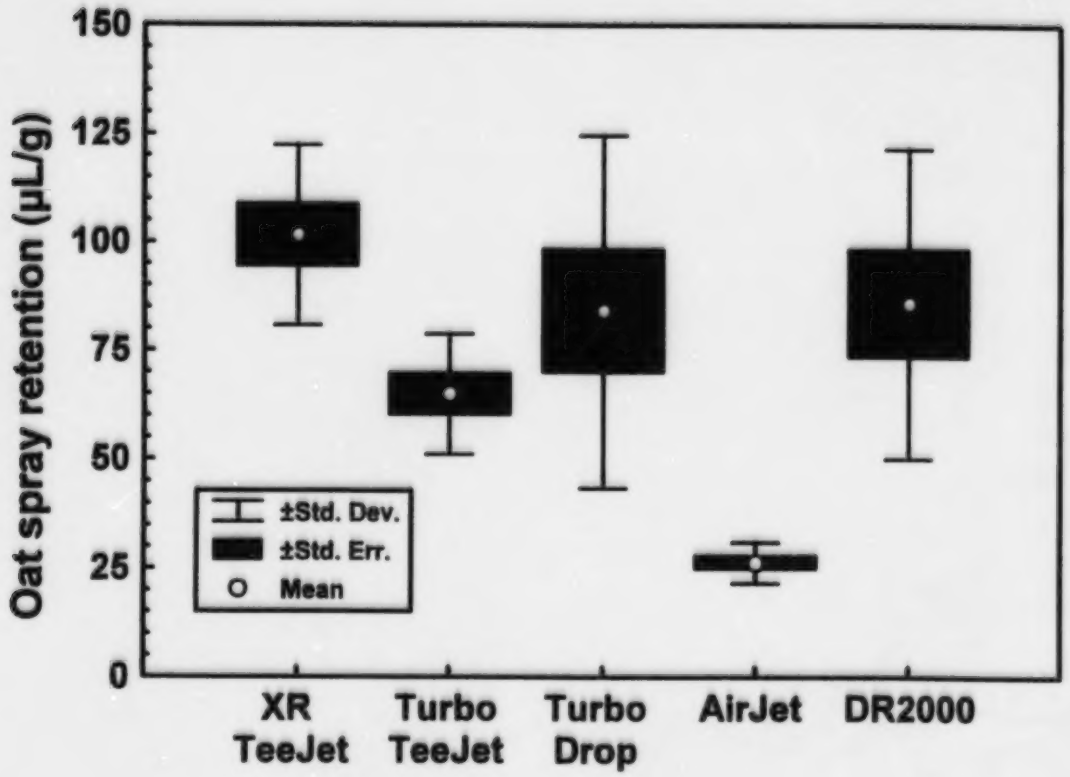

Figure 18: Mean spray retained by oats from 5 atomization systems in Retention Experiment 1.

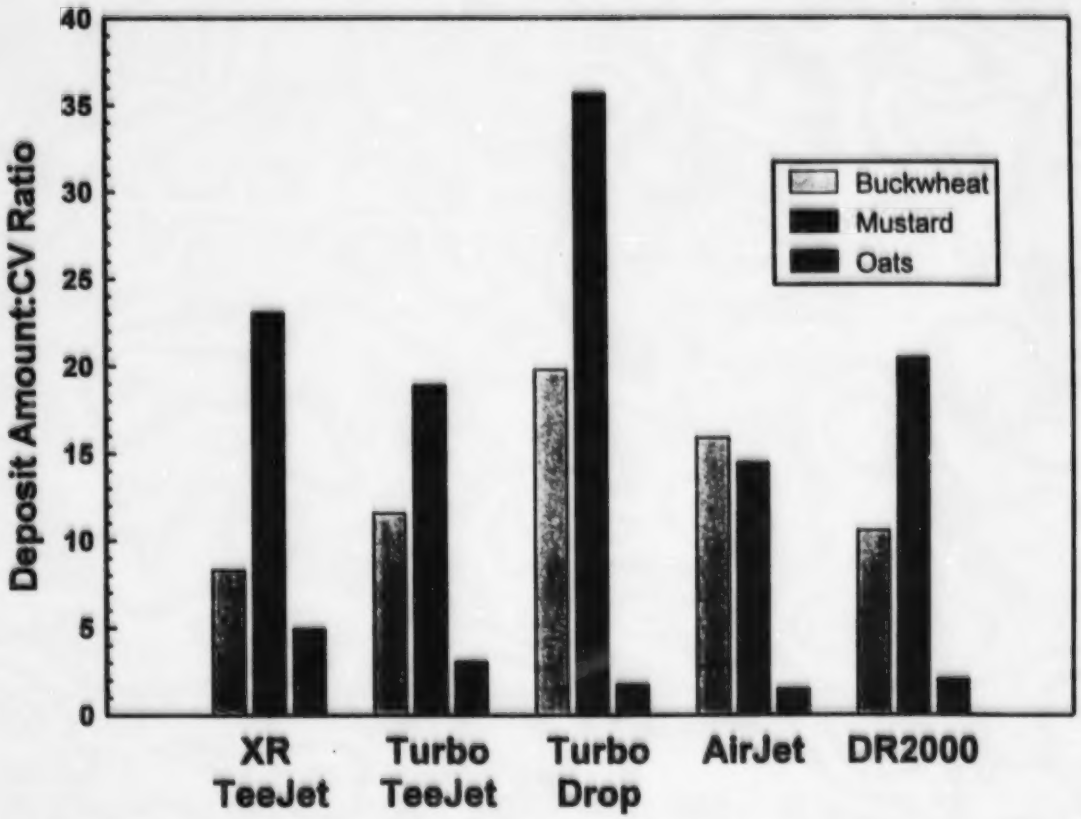

Figure 19: The ratio between plant spray retention (µL/g dry weight) and plant deposit variability (CV) for three simulated weed species in response to application method, Retention Experiment 1.

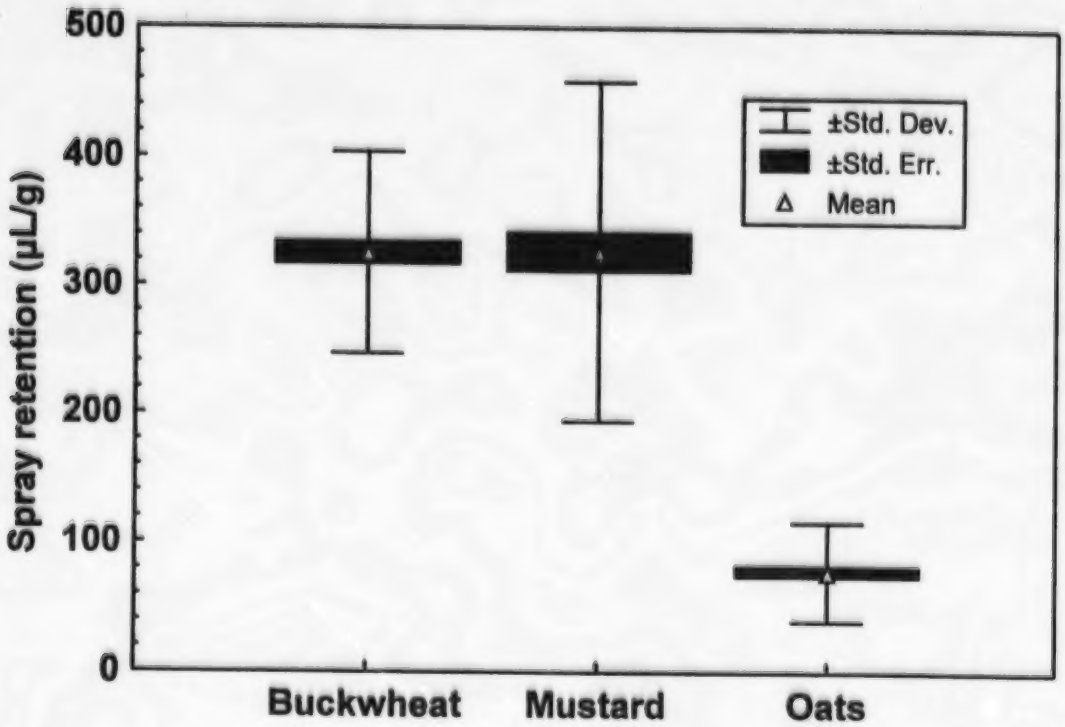

Figure 20: Mean spray retained by three simulated weeds in Retention Experiment 2.

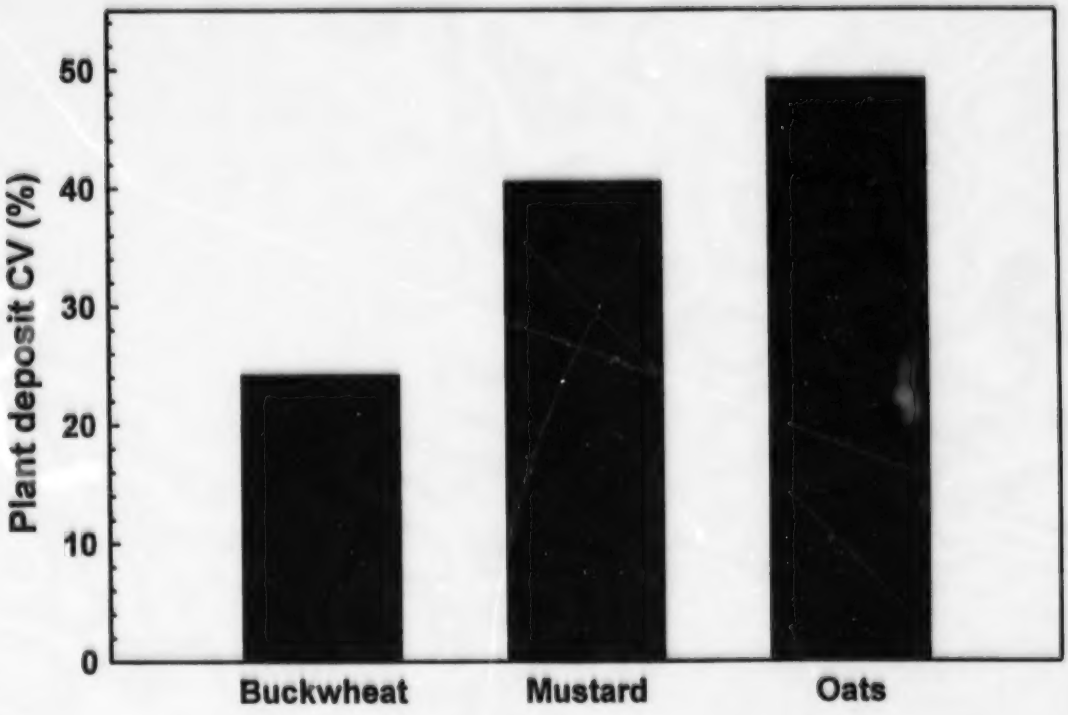

Figure 21: Spray deposit variability (as coefficient of variation, CV, with n=72) on three simulated weeds in Retention Experiment 2.

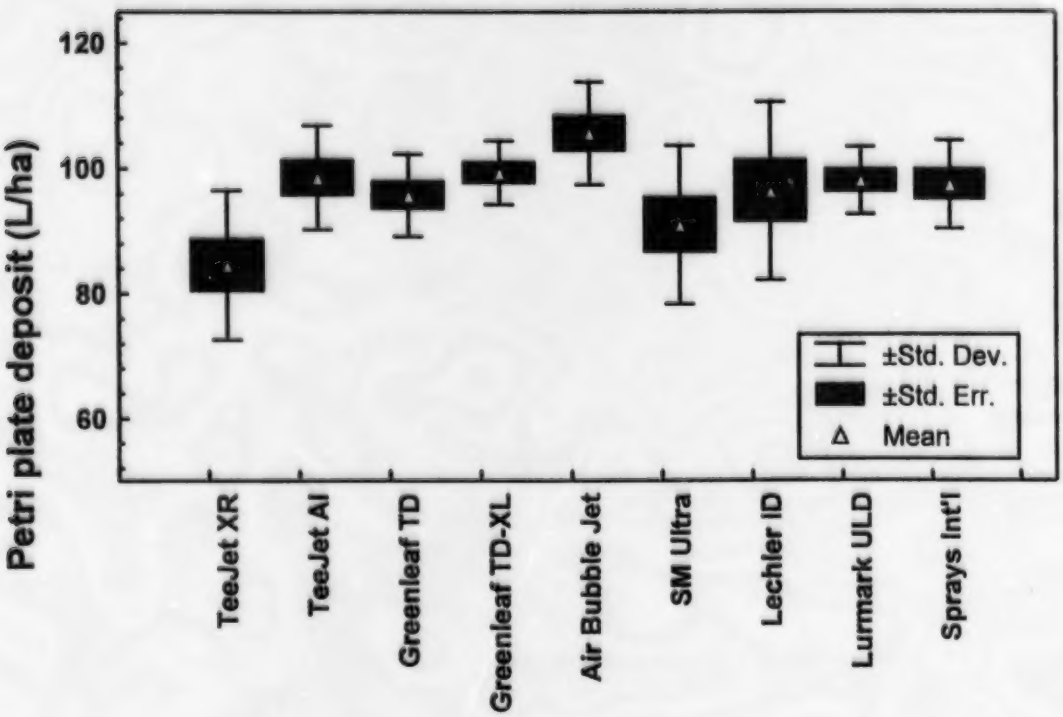

Figure 22: Mean spray delivery to petri plates in the spray swath for 9 nozzles, Retention Experiment 2.

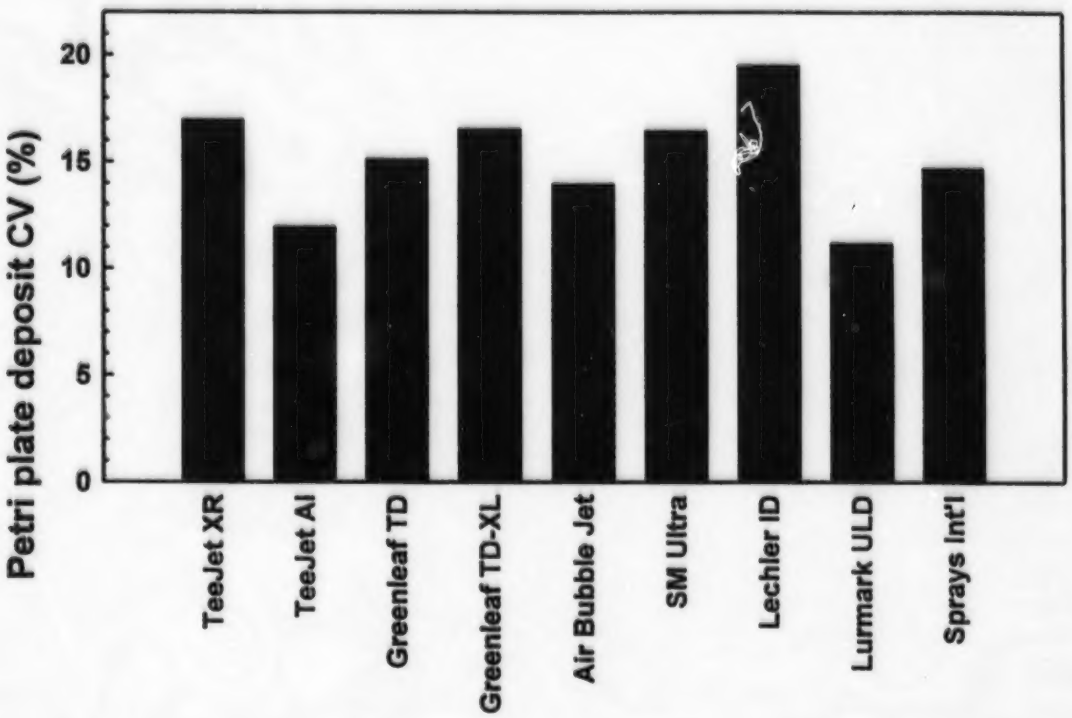

Figure 23: Spray deposit variability (as coefficient of variation, CV, with n=24) on petri plates in the spray swath for 9 nozzles, Retention Experiment 2.

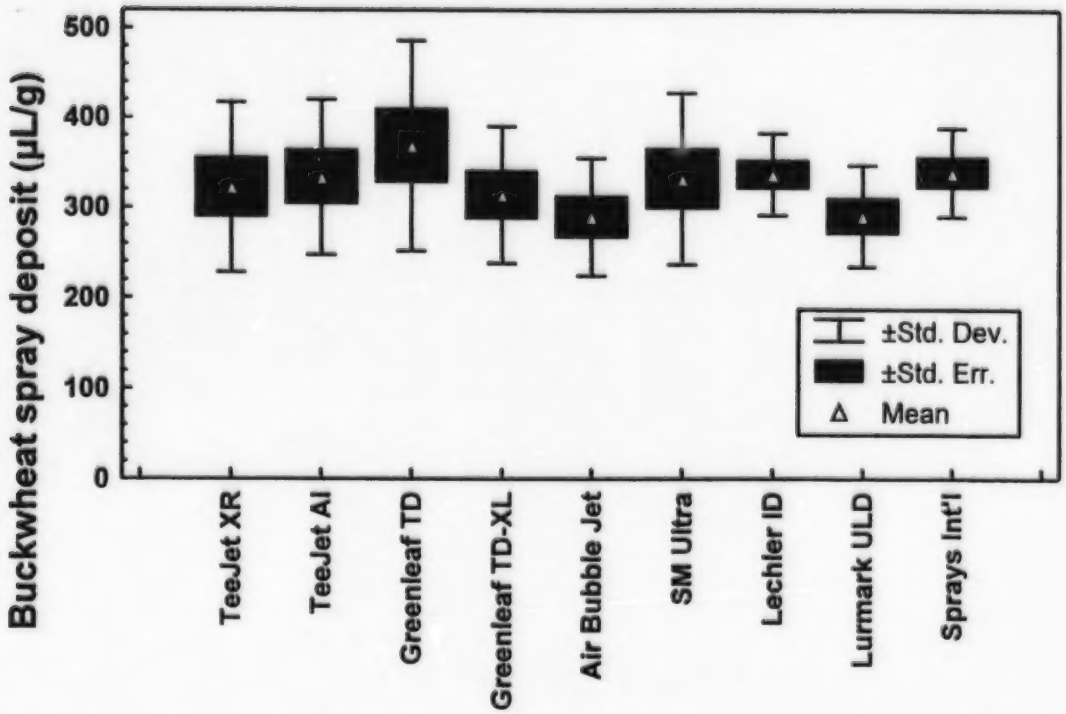

Figure 24: Mean spray retained by buckwheat from 9 nozzles in Retention Experiment 2.

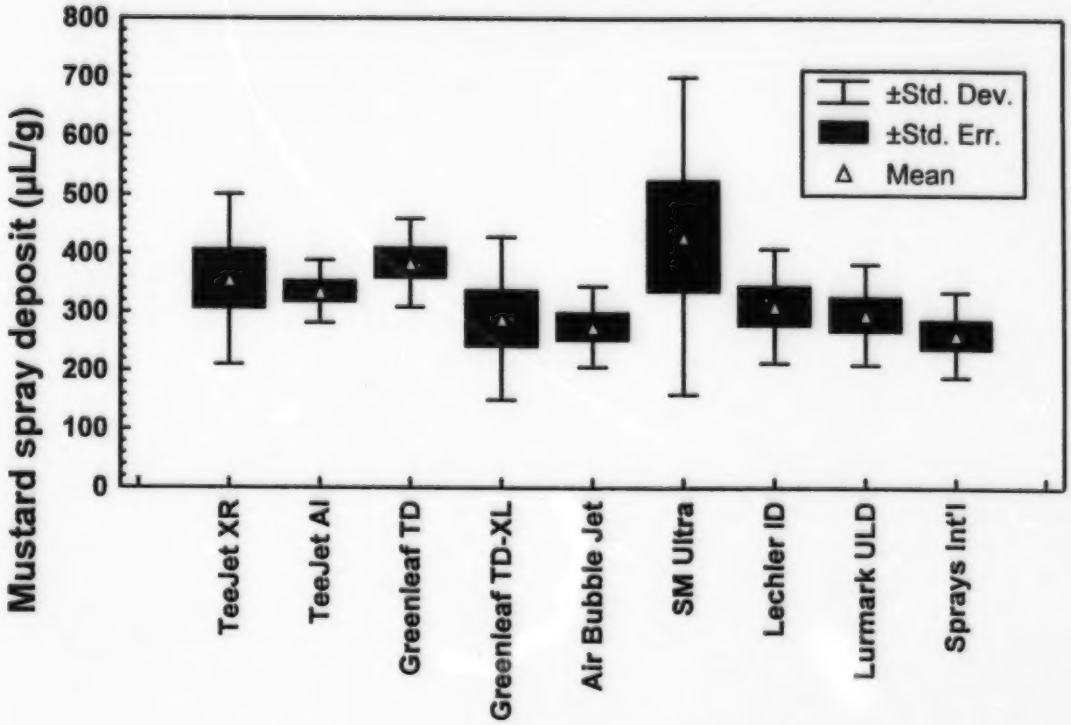

Figure 25: Mean spray retained by mustard from 9 nozzles in Retention Experiment 2.

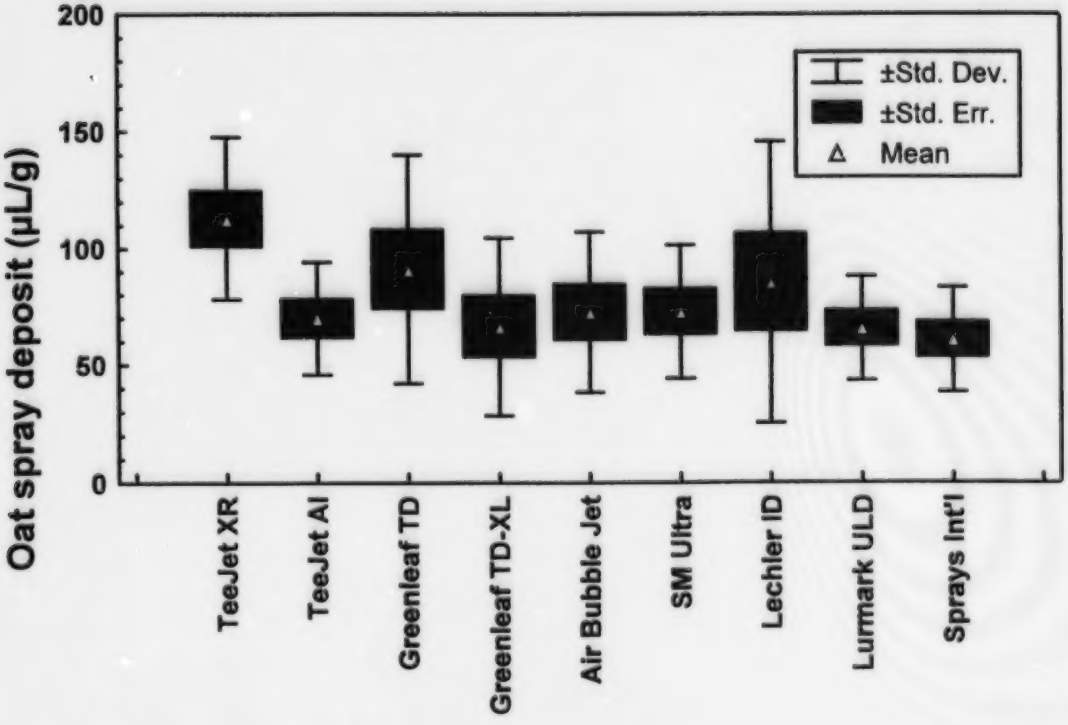

Figure 26: Mean spray retained by oats from 9 nozzles in Retention Experiment 2.

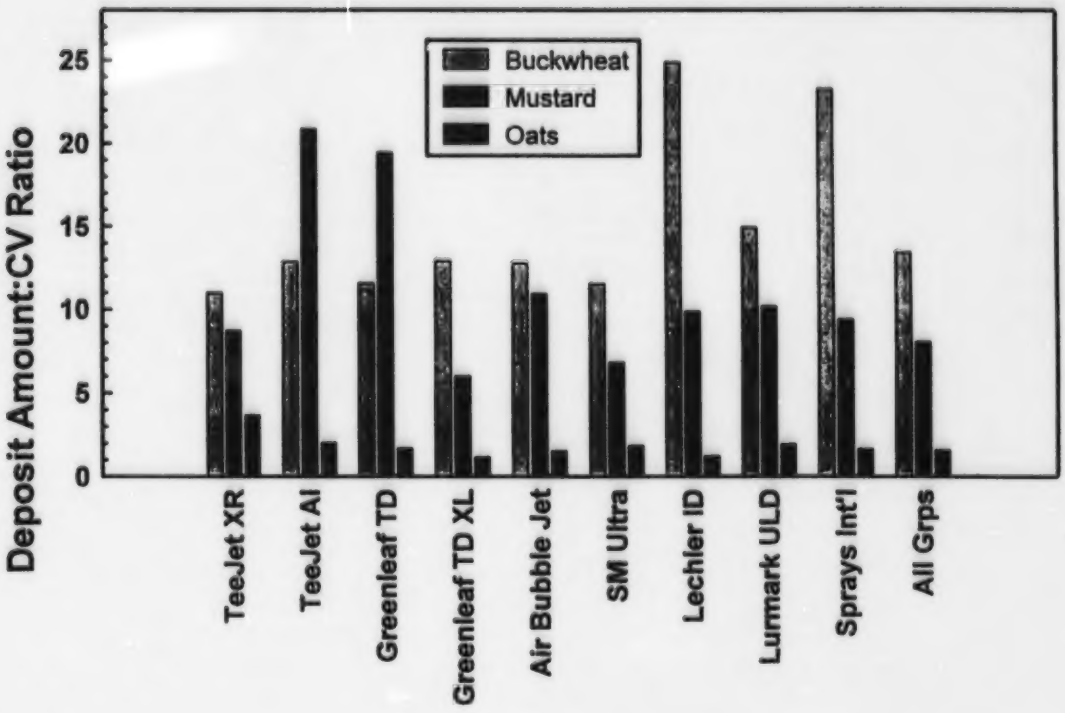

Figure 27: The ratio between plant spray retention (µL/g dry weight) and plant deposit variability (CV) for three simulated weed species in response to application method, Retention Experiment 2.

Project Activities and Achievements

This project is now complete. Data will be presented in scientific manuscripts for submission as publications over the next year.

Publications:

1. Wolf, T.M. 1998. Pest control with sprays - a look into the past and a glimpse of the future. Pesticide Formulations and Application Systems: 18th Volume, ASTM STP 1347, J.D. Nalewaja, G.R. Goss, and R.S. Tann, Eds. American Society for Testing and Materials, pp. 47-57.
2. Wolf, T.M., Caldwell, B.C., Grover, R., and Maybank, J. 1998. New options for low drift spray application. Proceedings, Soils and Crops '98, University of Saskatchewan, Saskatoon, SK, February 18-20, 1998.
3. Wolf, T.M. and Downer, R.A. 1998. Developing criteria for the ideal agricultural spray - a biologist's perspective. ILASS Americas, 11th Annual Conference on Liquid Atomization and Spray Systems, Sacramento, CA, May 17-20, 1998, pp. 3-10.
4. Wolf, T.M. Update on ground application technology. Proceedings of the 26th Annual Conference of the Prairie Potato Council, Feb. 5-7, 1998, Brandon, MB, pp. 110-114.
5. Wolf, T.M. New developments in sprayer technology. Proceedings, 1998 Pesticide and Fertilizer Dealers Update Workshop, Portage la Prairie, MB, February 25, 1998.
6. Wolf, T.M. 1998. Making sense of new nozzle choices. Joint publication of Manitoba Agriculture, Saskatchewan Agriculture and Food, and Alberta Agriculture, Food, and Rural Development, 6 pp. (40,000 copies printed).
7. Wolf, T.M., Lafond, G., Caldwell, B.C, and Johnson, E. 1999. Weed control in herbicide tolerant canola with low-drift sprays. Poster presented at Expert Committee on Weeds Annual Meeting, Ottawa, ON, Nov.29-Dec. 1, 1999 (Prize for best poster)
8. Wolf, T.M., Caldwell, B.C, and Byer, K.N. Herbicide efficacy with low-drift nozzles. Poster presented at Weed Science Society of America Annual Conference, Toronto, ON, Feb 6-9, 2000.

Media Exposure:

23 media interviews relating to spray technology issues were provided for print and radio media. All these interviews included research information derived from this ADF-funded project.

1. Interviewed by Helen McMenamin of the Top Crop Manager for article featuring new trends in spray technology, January, 1997 (Article in March, 1997 issue).
2. Interviewed by Lorne McClinton of AgriFamily Business Magazine on spray drift management, February, 1997 (Article in February, 1997 issue)
3. Interviewed by Karla Schoenfeld of Agro Plan Report on low-drift spray technology, April, 1997.

4. Interviewed by CBC radio in response to Research Letter released in June, 1997, regarding new spray-drift reducing technology. Interview clip was aired on CBC Radio 540 during morning edition.
5. Interviewed by Margaret Hryniuk, Sask. Ag and Food, for two stories featured in Farm and Food Reports: "Spray Drift Can be Prevented" (May 4, 1998); "Reducing Herbicide Drift from High Clearance Sprayers (May 18, 1998)
6. Interviewed by Janet Kanters for CPM article featuring venturi nozzle technology, September, 1998.
7. Interviewed by Bob Webber for Country Guide article on spray drift, January, 1998.
8. Interviewed Canola Council of Canada for radio advertisement segments featuring CARP-sponsored research activities, February, 1998.
9. Interviewed by Angie Tousaw of AdFarm on spray drift management with new technology, February, 1998.
10. Interviewed by John Dietz for Westco magazine regarding improved application precision with new spray options, February, 1998.
11. Interviewed by Vivian Webb for an article on venturi nozzles and the ECW Low Drift Nozzle Initiative, February, 1998..
12. Interviewed by Glenda-Lee Allan of Golden West Broadcasting for two stories on strategies to reduce drift incidences March, 1998.
13. Brian Lyster, Country Guide, for article on efficacy implication of low-drift nozzles (January 13), 1999.
14. Bill Tindall of AgRetailer magazine (US publication), sole Canadian quoted among several US researchers ("Fine tuning pesticide application – inexpensively"), Jan 26, 1999.
15. Mike Holmberg, Successful Farming (US publication), sole Canadian quoted among several US researchers ("Venturi nozzles"), Jan 27, 1999.
16. Robin Hoffman, Farm Journal (US publication), sole Canadian quoted among several US researchers ("Death, Taxes, and Spray Drift"), February, 1999.
17. Ron Lyseng, Farming Magazine (invitation to publish feature article "Spray Drift - Just say NO" for March, 1999 edition of magazine, reaches 85,000 subscribers in Canada, February, 1999).
18. Marshall Perrin, Agriculture Communications Section, AAFC (provide free radio interviews to agricultural stations), on venturi nozzles for drift protection, February 16, 1999).
19. John Dietz, freelance writer, unknown magazine (March 25, 1999)
20. Maggie van Camp of Farm Business Communications, United Grain Growers (April 20, 1999)
21. "Mo", of Quarry Integrated Communications, for an article on spray drift in AgWorld magazine (May 27, 1999)
22. Glenda-Lee Allan of Golden West Broadcasting on strategies to reduce drift incidences (June, 1999).
23. Glenda-Lee Allan of Golden West Broadcasting on venturi nozzle to reduce drift (March 2, 2000).

Presentations:

Presentations relating to spray technologies which were directly or partly related to ADF-funded research data were made at over 50 events over the course of this project, reaching approximately 5215 people.

1. "Political and Technological Shifts in Spraying". Canadian Association of Agri-Retailers Annual Convention and Trade Show, February 9, 1997, Saskatoon, SK (150 people).
2. Herbicide Mode of Action Course organized by Alberta Agriculture in, teaching aspects of spray application and adjuvant use, Feb. 18-20, 1997, Edmonton, AB (75 people).
3. Westco Aces, Information Update Meeting, "Trends and Issues in Spray Application for 1997", March 4, 1997, Calgary, AB (20 people).
4. U of S Crop Science Seminar, "Spray Application Technology - the Science Behind Progress", March 5, 1997, Saskatoon, SK (30 people).
5. Canadian Federation of Agriculture, Together for Tomorrow Forum: "Developments in the Application of Crop Protection Agents", March 7 & 8, 1997, Winnipeg, MB (100 people).
6. "What's new in spraying?" Future-Four Agro, March 11, 1997, Macoun, SK, (75 people).
7. Certified Crop Advisor Training Session organized by Westco, teaching drift management and adjuvant use, March 17-21,1997, Saskatoon, SK (100 people).
8. "Technological and political shifts in spraying", Bean Day, Manitoba Agriculture, March 20, 1997, Carman, MB (300 people).
9. "The pros and cons of cutting herbicide rates with new spray technology". DuPont producer meeting, March 25, 1997, Saskatoon, SK (40 people).
10. "Drift issues with high clearance sprayers" Dave's Fertilizers, March 26, 1997 , Carrot River, SK (35 people).
11. Technical Update seminar provided to Novartis' western Canadian staff, focusing on high clearance application and drift management, April 24, 1997, Calgary, AB (40 people).
12. "Future Sprayers - Design Considerations for the Machinery Industry" John Deere, Des Moines Works, Round Table Discussion, July 16, 1997, Des Moines Iowa (30 people)
13. "Pest Control with Sprays - A Look into the Past and a Glimpse of the Future", Opening paper for Pesticide Application Session at 18th Symposium on Pesticide Formulations and Application Systems: The Changing Face of Agriculture. San Diego, CA, Oct. 14-15, 1997 (250 people).
14. "Spray nozzles and drift control, Saskatchewan Soil Conservation Association Agrologists Workshop, November 18, 1997, Saskatoon, SK (120 people).
15. "Spray drift - the search for practical solutions". PMRA Alternatives Division, F/T/P Committee on Pest Management and Pesticides Stakeholders Session, November 26, 1997, Edmonton, AB (25 people).
16. "Update on Ground Application Technology". Manitoba Horticulture Production Days. Victoria Inn, February 5-7, 1998, Brandon, MB (125 people).
17. "New nozzle technologies for spray drift management". Agronomy update, February 17, 1998, Weyburn, SK (75 people).

18. "New Developments in Sprayer Technology." 1998 Pesticide and Fertilizer Dealers Update Workshop, February 25, 1998, Portage la Prairie, MB (200 people).
19. "On-Target Spray Application". Monsanto Agronomy Workshop, February 27, 1998, Kelowna, BC (50 people).
20. "New nozzle technologies for spray drift management". Customer appreciation meeting, Pioneer Coop, March 4, 1998, Swift Current, SK (60 people).
21. "Understanding the dose transfer of pesticides". Agronomy Training Session organized by U of S Extension Division, March 20, 1998, Saskatoon, SK (150 people).
22. "Optimizing spray application with new technologies". Agronomy Workshop organized by PARI Conservation Tillage Farm, March 24, 1998, Prince Albert, SK (70 people).
23. Technology update on effective operation of high clearance sprayers to Cargill custom applicators, March 27, 1998, Saskatoon, SK (45 people).
24. Day long seminars and demonstrations to directors, section heads, and coordinators of Pest Management Regulatory Agency, April 14-15, 1998, Ottawa, ON (50 people).
25. Demonstration of venturi nozzle technologies for DuPont, Cargill, and Federated Cooperatives, May 6, 1998, Hanley, SK (15 people).
26. Sprayer calibration training for BASF field staff, May 7, 1998, Saskatoon, SK (20 people).
27. "Developing criteria for the ideal agricultural spray - a biologist's perspective". ILASS Americas, 11th Annual Conference on Liquid Atomization and Spray Systems, May 17-20, 1998, Sacramento, CA (200 people).
28. "Optimizing spray placement of Roundup". Monsanto Pre-Harvest Primer, July 7, 1998, Saskatoon, SK (80 people).
29. Technical update and demonstration of venturi nozzle technology provided to BASF's western Canadian staff, September 9, 1998, Calgary, AB (40 people).
30. Update on venturi nozzle technology. Westco ACES Technical meeting, October 1, 1998, Regina, SK (25 people).
31. Update on venturi nozzle technology. Saskatchewan Soil Conservation Society Round Table Discussion, October 28, 1998, Saskatoon, SK (15 people).
32. "Nozzles Help You Say "NO" to Spray Drift", 27th SK Alfalfa Seed Growers Annual Meeting, Jan. 12, 1999, Saskatoon, SK (50 people).
33. "New Spray Nozzles – Better Weed Control with Less Drift", Crop Talk '99, Jan. 20, 1999, Prince Albert, SK (120 people).
34. "Efficacy of Venturi Nozzle Technology", SAF 1999 Industry Update, Jan 28, 1999, Saskatoon, SK (85 people)
35. "Sprayer Tips and Nozzles", Westco Production Seminar, Feb. 2, 1999 , North Battleford, SK (100 people).
36. "Sprayer Nozzles", SSCA Annual Conference, Feb 17-18, 1999, Saskatoon, SK (750 people).
37. "Watch that spray drift! Are venturi nozzles the answer?" South Central Ag Day '99, Feb 25, 1999, Carman, MB (200 people).

38. "Taking advantage of new spray technology". Four training sessions provided for Cyanamid Crop Protection Workshop, February 26, 1999, Winnipeg, MB (100 people).
39. "Efficacy Classification?" Spray Quality for Agricultural Nozzles – A Workshop for Manufacturers of Spraying Equipment. Match 2, 1999, Tampa, FL (50 people).
40. "Low-drift nozzles – what are they? Do they work? Are they worth it?" Agronomy School, Pioneer Coop, SK, March 10, 1999, Swift Current (150 people).
41. "What's new in spray nozzle technology?" Crop Decisions '99, organized by SAF, March 12, 1999, Humboldt, SK (20 people).
42. "Are venturi nozzles for you?" Producer meeting organized by Agri-Team Services, March 15, 1999, Speers, SK (30 people).
43. "Venturi nozzles" Monsanto applicator meeting April 16, 1999, Saskatoon, SK (20 people).
44. "Selecting the Right Nozzle for the Job". Sask Wheat Pool Custom Applicator Training, April 15, 1999, Saskatoon, SK (30 people).
45. "Optimizing Performance of Low-Drift Nozzles". CAAR CCA Training, Nov. 8, 1999, Saskatoon, SK (100 people).
46. "Agriculture, Environment, and Pesticide Sprays: Building a Scientific Basis for Regulatory Approaches". Civil Nooner, one of a series of invited seminars by U of S Dept of Civil Engineering, Nov 10, 1999, Saskatoon, SK (50 people).
47. "Venturi Nozzles – When to Use Them, When to Lose Them". Saskatoon Crop Production Show, Jan 11 & 12, 2000, Saskatoon, SK (100 people total).
48. "Venturi Nozzles - Features, Performance, Value". Four seminars held for Federated Coop in Manitoba, Saskatchewan, and Alberta , February, 2000 (120 people total).
49. "Spray Nozzles and Drift - Selecting the Right Nozzle for the Job". Training seminar for Westco and Lloydminster Joint Venture clients, Feb 15, 2000, Lloydminster, AB (25 people).
50. "Spray Nozzles and Air Assist - Selecting the Right Tool for the Job". All West Sales Crop Protection Workshop, Feb 23, 2000, Rosetown, SK (75 people).
51. "Low Drift Nozzles and Buffer Zones - A perfect Match". Dow AgroSciences Agronomy Workshop, Feb 29, 2000, Red Deer, AB (125 people).
52. "Making Sense of New Nozzle Choices". SAF Extension Workshops in Kindersley and Eston, SK, March 1, 2000 (75 people total)
53. "Update on Low-Drift Nozzles". Pioneer Coop Agronomy Days, March 2, 2000, Swift Current, SK (150 people).
54. "Making Sense of New Nozzle Choices". SAF Extension Workshops in Outlook and Davidson, SK, March 3, 2000 (50 people total).
55. "Making Sense of New Nozzle Choices". SAF Extension Workshop in Harris, SK, March 8, 2000 (30 people).

Field Tours:

Field tours or sprayer demonstrations were conducted throughout Saskatchewan during the course of the project, reaching approximately 2415 people.

1. Featured tour stop at Saskatoon Agronomy Workshop, July 10, 1997 (100 people).
2. Featured tour stop at Indian Head IHARF Field Tour, demonstrating new spray technologies, July 22 & 23, 1997 (400 people).

3. Featured tour stop at 1997 AAFC Machinery Dealers' Field Day, demonstrating new spray technologies, Melfort, SK, August 12, 1997 (30 people).
4. Featured tour stop at 1998 Saskatchewan Soil Conservation Society Zero-Till Field Day, Seager Wheeler Farm, Rosthern, SK, June 6, 1998 (200 people).
5. Featured tour stop at 1998 Saskatchewan Alfalfa Seed Growers Field Day, demonstrating new low-drift nozzles, Melfort SK, July 16, 1998 (75 people).
6. Featured tour stop at 1998 Saskatchewan Weed Tour at U of S Kernen Research Farm and AAFC Farm, Saskatoon, SK, July 17, 1998 (60 people).
7. Featured tour stop at 1998 Indian Head IHARF Field Tour, demonstrating new spray technologies, July 21 & 22, 1998 (400 people).
8. Featured tour stop at 1998 Melfort Field Tour, demonstrating new spray technologies, July 23, 1998 (300 people).
9. Featured tour stop at 1999 AAFC Scott Field Day, Scott, SK, July 14, 1999 (300 people).
10. Featured tour stop at Indian Head IHARF Field Tour, demonstrating new spray technologies, July 20 & 21, 1999 (200 people).
11. Featured tour stop at 1999 Melfort Field Tour, demonstrating new spray technologies, July 22, 1999 (200 people).
12. Featured tour stop at 1999 Mustard Growers Field Day, Saskatoon, SK, July 28, 1999 (150 people).

Indications for Further Development

This research has helped make low-drift spraying a credible and popular alternative to conventional spray technologies. Since only two herbicide products were evaluated in these studies, new research investigating other herbicide modes of action has recently been funded by ADF (Wolf, Holm, Hall, and Van Acker, "The Impact of Herbicide Mode of Action on Low-Drift Spray Effectiveness"). Such research will continue to provide updated information to Saskatchewan producers as new nozzles and use patterns emerge, and ensure continued guidance in the use of environmentally friendly spray technologies.

New priorities are now to develop spray drift models that incorporate these new technologies into environmental risk assessments. The drift models currently used by the Pest Management Regulatory Agency (PMRA) do not credit applicators for low-drift spray methods, resulting in large buffer zones around sensitive areas such as sloughs or shelterbelts. Models that are relevant to Saskatchewan conditions are required for accurate buffer zone calculations.

Information of Benefit to Producers, Processors, or Government

The main conclusion from these studies for all clients is that low-drift pesticide application is a viable alternative to conventional spray application methods in Saskatchewan. However, proper implementation of the technologies is important to maintain the technology's viability. There is the danger that improper use of low-drift sprays (i.e., low pressures and/or very coarse

sprays on grassy weeds) will result in reduced control, reducing the satisfaction of applicators and retailers with such technology. It is possible that use of these nozzles will be discouraged based on such experiences. It is imperative that a continued effort be made to identify the suitability of low-drift sprays in pest management so that these sprays will remain usable tools for Saskatchewan farmers. Properly supported through research and extension efforts such as those represented by this study, low-drift spraying will be standard practice and will become a good example of environmental stewardship by Saskatchewan's agricultural industry.